LLOYD'S REGISTER STAFF ASSOCIATION

SESSION
1964 - 65

TRANSACTIONS

OF

LLOYD'S REGISTER STAFF ASSOCIATION

VOLUME 35

1964-65

71 FENCHURCH STREET, LONDON, E.C.3

OFFICERS OF THE ASSOCIATION

President:

S. Archer

Committee:

G. Buchanan

H. B. Siggers

C. Dearden

E. L. Knowles

J. Shaw

R. G. G. Hobbs

R. E. Lismer

S. P. Rooke

J. M. Bates

A. G. Kershaw

I. R. McNab

Honorary Secretary:

F. H. Atkinson

Asst. Honorary Secretary:

L. J. Crighton

CONTENTS

For Private Circulation amongst the Staff only

Lloyd's Register Staff Association

Session 1964 - 65

Paper No. 1

13 % CHROMIUM STEEL WATER TURBINE CASTINGS IN SWITZERLAND AND THEIR REPAIR BY WELDING

by

R. F. MUNRO

LLOYD'S REGISTER OF SHIPPING

71, Fenchurch Street, LONDON, E.C.3

13 % CHROMIUM STEEL WATER TURBINE CASTINGS IN SWITZERLAND AND THEIR REPAIR BY WELDING

By R. F. Munro

FOREWORD

When a steel founder can be sure of producing absolutely sound castings every time a furnace is tapped, especially if his castings are of such complex form as Francis runners or Pelton wheels and his material 13 % chromium steel, he may also be certain that much of the interest has gone out of the work of his resident Surveyor!

The steel founders' Valhallah is not yet here however, and the Surveyors in attendance at such works can be sure of being faced with many and varied problems in connection with repairs.

An advanced steel foundry with a considerable output of large alloy steel castings for water turbines builds up enormous experience of repairs by welding of what may come to be regarded as routine casting defects.

Correct welding techniques have been developed and will result in successful repairs under the ideal conditions which should obtain in the steel foundry.

Service failures at the power stations rarely come to the notice of the Surveyors and the example included here may prove of interest.

The paper which follows is the result of the Author's personal experience in the large modern steel foundries in Switzerland and includes the gleanings of endless discussions with the experienced personnel directly concerned with the production of these castings.

It also draws from his observation of conditions prevailing in water power stations high in the Alps and on the great rivers Rhine and Rhone.

It is not claimed that anything new will be found in the paper, but it is felt that some repetition of basic principles is justified if only on the grounds that some colleague may find something to help him when faced with a welding problem in 13 % chromium steel.

It has been found convenient to divide the paper into two sections, dealing with production and casting repairs at the foundries, and repair work at the power stations respectively. The description of repairs by welding involves much that is common to both sections.

Before passing on to the short paper which follows, the Author wishes to draw attention to the classic paper which Mr. T. W. Bushell presented to the Staff Association ten years ago on "Modern Foundry Practice".

So much of what he wrote then still applies to-day, and so comprehensive was his treatment that it is with some hesitation that this small addition to the subject is offered.

IN THE FOUNDRY—PRODUCTION

13 % chromium steel is a martensitic steel, the mechanical properties of which are obtained by air hardening, i.e. tempering from 1050° C. in air, followed by annealing at about 700° C., again cooling in air. Owing to its good resistance to cavitation, this alloy steel has become perhaps the most popular at the present time for all types of water turbine runners.

(a) Melting

Basic-lined electric arc furnaces are used in this country by firms engaged in the regular production of steel castings for water turbines. Capacities range from 3 to 30 tons, the furnaces being provided with horizontally swinging covers for top skip charging which results in great economy of time and arduous labour.

The 30 tons capacity furnace is equipped with an A.S.E.A. magnetic stirring device which consists fundamentally of a coil fixed below the furnace shell and through which flows an alternating current of very low frequency—roughly one cycle per second. By operating this device the molten steel is caused to circulate in such a way that the slag is brought to the surface where it can be readily removed.

The circulation of the melt is reversible in direction and can be caused to operate in both the vertical and horizontal planes.

Proper stirring is desirable to expedite the reactions between slag and molten steel and also for even distribution of the alloying additions.

Since really effective stirring of large heats by hand is a difficult, arduous, and slow operation almost impossible to

Table I.—Nominal Composition of Current Alloys used for Water Turbines

Material	C %	Mn %	Si %	Cr %	Ni %
13% Cr-steel	0.10	0.5	0.4	12.5	0.9
18% Cr/8% Ni-steel	0.07	0.5	1.0	18.0	9.0
2% Ni-steel	0.24	0.7	0.3	0.2	2.0
1.5% Mn-steel	0.24	1.6	0.3	0.2	0.4
Plain carbon steel	0.21	0.7	0.3	0.2	0.4
Al-bronze	Al 10.0	Fe 8.0	Mn 5.0	Ni 2.0	Cu Remainder

Table II.—Mechanical Properties of Current Alloys used for Water Turbines

Material	Minimum Yield Point	Ultimate Tensile Strength	Minimum Elongation L=5d	Minimum Charpy Impact (keyhole)	Brinell Hardness	Fatigue Limit
	kg/mm²	kg/mm²	%	kg/cm²		kg/mm²
13% Cr-steel	45	65–75	15	4	190–230	~30
18% Cr/8% Ni-steel ...	15	40–50	30	18	130–170	~13
2% Ni-steel	35	55–65	18	6	155–195	~22
1.5% Mn-steel ...	34	50–60	22	6	140–180	~18
Plain carbon steel ...	23	45–55	22	6	125–165	~20
A1-bronze hard ...	30	60–70	7	2	190–230	~15

execute properly, a magnetic device is of great help and is applied here very successfully.

All heats in these foundries are melted with the aid of oxygen, but in principle the refining practice has remained the same over the years, operating with two slags.

As a point of interest, one foundry has a mile-long oxygen pipe providing a direct supply from the gas manufacturer's plant.

The temperature of the steel is measured with immersion pyrometers in the furnace and also in the ladle at the pouring stations.

Chemical compositions are checked during the melting period by rapid analytical methods, namely, the direct reading spectrograph, which gives all the required information within a few minutes and protects the founder against possible errors in the composition of the charge, and allows adjustments to be made before tapping the furnace.

Active research work is at present being directed at the problems of gas in molten metal with a view to determining its nature and cause, and to finding means for eventual control of such gas with resulting improvements in the castings.

(b) Pouring

One of the principal difficulties in the casting of this material is the fact that the pouring temperature is critically important.

The difference in viscosity at pouring temperature between a normal carbon steel and 13 % chromium steel can be compared with that between milk and honey!

The actual temperature at pouring is selected having consideration to the size and complexity of the casting.

The limiting factors are, on the one hand—too low a temperature will cause the formation of oxides which cannot rise into the heads before solidification takes place; and on the other hand—too high a casting temperature will result in serious difficulties with the core and moulding sands.

It is evident that great experience is required on the part of the steel founder, and much of this experience has been gained by cutting up and sadly contemplating his failures.

It also follows that the steel founders find it necessary to undertake much research into the nature and properties of core and moulding sands, as well as exercising the closest possible control over the electric furnace during the melting process.

(c) Sand

The preparation, quality control, and movement of core and moulding sand in the modern steel foundry has become highly mechanised.

Most of the hard and time-consuming work has disappeared from the moulding shop and to-day the moulding boxes are packed by "sand slingers" which hurl the previously prepared sand at very high velocity by means of a rotating wheel.

The speed of sand handling and the efficiency of sand preparation equipment have an important effect on the output of the foundry both in quantity and quality of the castings.

The type of equipment now in use is illustrated in diagrammatic form in Fig. 1, and its size and capacity will be appreciated from the following figures:—

Height of plant	72 feet
Sand throughput per hour	190 tons
Sand throughput per year	160,000 tons (moulding)
Sand throughput per year	12,000 tons (core)

The mixing of used sand, new sand, binders and additives, and the addition of water as found necessary is under fully automatic control from a central electronic station and can be followed by visual indications on an illuminated diagram.

It will be realised that this is a highly specialised branch of the steel foundry and it is intended to give here only an indication of what is involved.

The quality of castings and the proportion of rejects are largely determined by the grain structure of the core and moulding sands. To overcome the problem of variations in the sands delivered, special equipment has been installed to enable any grade of sand to be produced and deliveries to be graded according to the foundryman's requirements. A great economic advantage of this plant is that it can be used to recondition used sand from the foundry. Up to 10 tons of used sand per hour can be processed.

(d) Heat Treatment

(i) Castings. Furnaces large enough to accommodate the biggest castings which can be produced are a most essential part of the steel founders' equipment, and must be capable

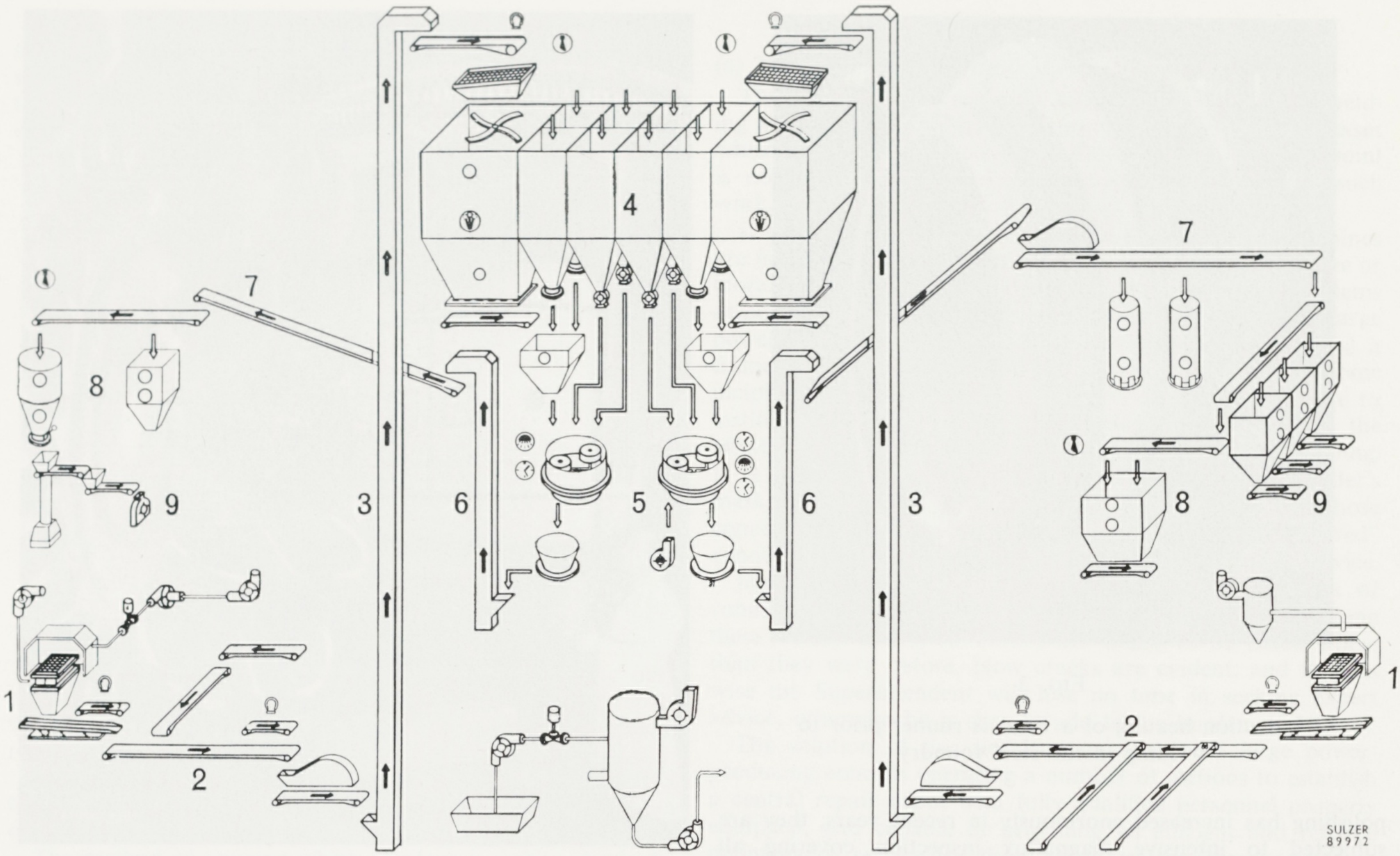


FIG. 1

SAND PREPARATION DIAGRAM FOR THE STEEL FOUNDRY

1. Shake-outs.
2. Used-sand return conveyors.
3. Bucket elevators for used sand.
4. Sand and binder silos.
5. Sand mixers.
6. Bucket elevators for prepared sand.
7. Conveyor belts.
8. Intermediate silos.
9. Moulding stations.

of close temperature control and regulation with recording pyrometers strategically located. For important heats thermocouples may be fixed directly to the castings.

Control of the furnaces can be arranged electronically by punched cards in accordance with the required heat-treatment programme arranged by the metallurgical staff, thereby ensuring that consistency of properties is obtained and the possibility of human error is eliminated.

(ii) FOUNDRY REPAIRS. Induction heating is applied very successfully to Francis and Pelton runners by which the whole casting can be brought to an even pre-heat temperature (200–400° C.) and maintained for as long as required to complete the repairs by welding (Fig. 2).

For relatively small local repairs to Pelton wheels and Kaplan blades pre-heating is normally achieved by the application of propane gas burners. These burners can also be used for stress relieving the finished welds. However, castings are also frequently raised to pre-welding temperature in the furnace and subsequently maintained by use of propane burners during welding.

(e) NON-DESTRUCTIVE TESTING

In this district the available aids to flaw detection range from a sharp pair of eyes assisted by various lenses and a hammer, through the full scope of modern equipment—magnaflux, penetrant dyes, ultrasonics, X-ray units, and radioactive isotopes, to a Betatron of 31 MeV which produces highly penetrating gamma radiation.

Present-day magnaflux techniques with very high amperage, (up to 4,000 amperes) are most searching and have a useful penetration below the surface of the material.

On sharply curving surfaces such as in Pelton wheel buckets the dry powder method is preferred, and the powder is carried evenly to the surface under inspection by a jet of low pressure compressed air.

Subsurface detection sensitivity has been shown to be in the ratio of 5:2:1 respectively for d.c., half-wave rectified a.c., and a.c. methods.

As soon as the castings leave the fettling bay, where incidentally, the amount of work devoted to high-pressure water washing, hand cleaning, shot-blasting, grinding and

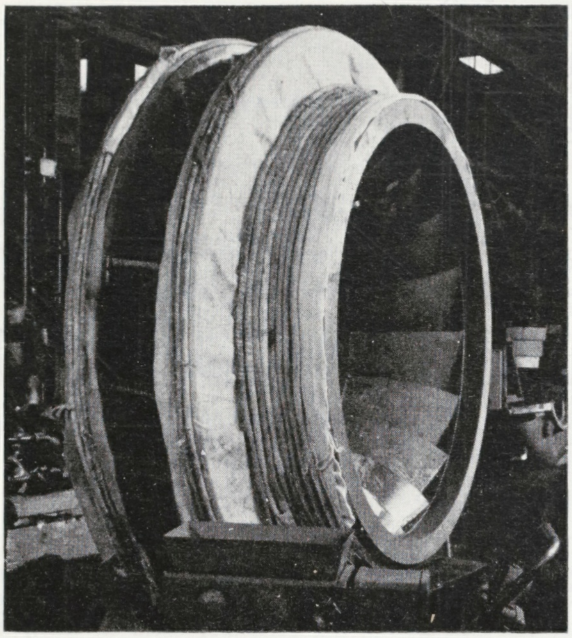


FIG. 2

Induction heating of a Francis runner prior to welding in the steel foundry

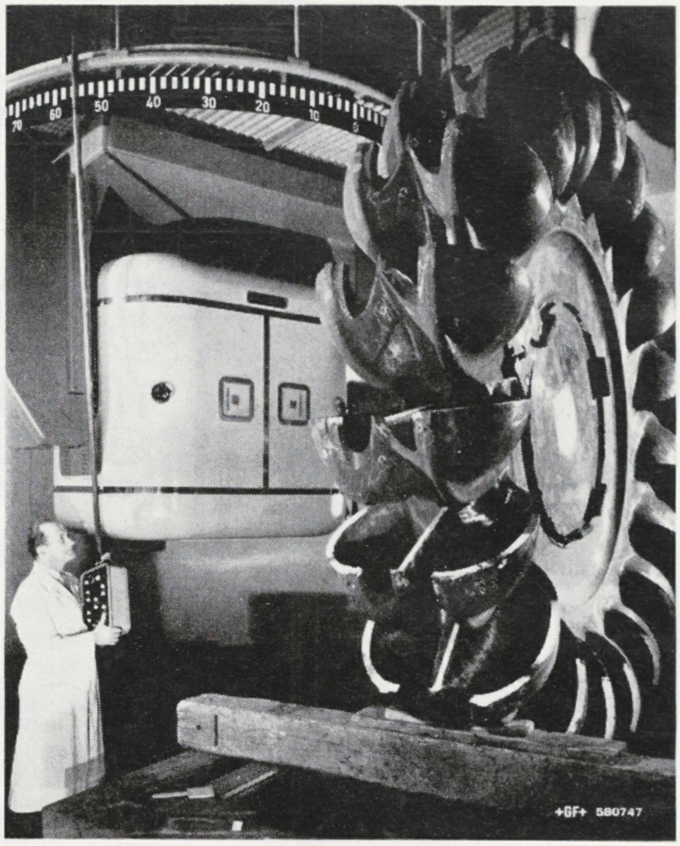


FIG. 3

Radiographic inspection of a Pelton wheel by means of a 31-MeV Betatron

polishing has increased enormously in recent years, they are subjected to intensive magnaflux inspection covering all changes of section and all positions which from experience are known to be likely to contain defects.

It is significant that the annual consumption of dry magnetic powder here by one foundry largely, but not exclusively engaged on the production of castings for water turbines, is almost one ton, and this figure is expected to be exceeded soon as even more magnaflux units are about to come into service.

The Betatron is in regular use. By the use of this apparatus it is feasible to examine thick-walled castings in relatively short times; moreover, by employing betatron radiation it is possible by making a single radiograph, to inspect castings which vary widely in wall thickness (Fig. 3).

Further advantages of betatron radiography derive from the very small target of the apparatus which allows extremely fine focussing. This permits details of defects to be enlarged and reproduced with a highly desirable sharpness of definition, and with a sensitivity of 0·5 per cent of the wall thickness.

It has been suggested to me on more than one occasion that in the days before "Non-Destructive Testing" there was not nearly so much trouble with steel castings! The obvious answer to this is that producers and consumers alike have been quick to take advantage of all the new techniques which have been developed because their proper application and interpretation is sure to result in a superior end-product.

Steel founders invest considerable capital in providing such complete inspection facilities because they are just as interested as the inspection authorities in avoiding the difficulties that arise when defects are found in castings at a late stage of machining.

Profits tend to shrink if teams of highly paid welders have to be sent to remote engineering works to execute repairs, or alternatively, if large castings have to be returned to the founder's works at his expense.

The resident Surveyor with his quite impartial attitude can prove of great assistance to all concerned, particularly when delivery dates become critical and commercial considerations begin to weigh heavily on the technical personnel with whom he is in daily contact.

(f) REPAIR WELDING

When a defect has been located by one or other of the above-mentioned methods of flaw detection, which should always be regarded as complementary, it is most important that rewelding should not be instituted until all traces of the flaw have been removed.

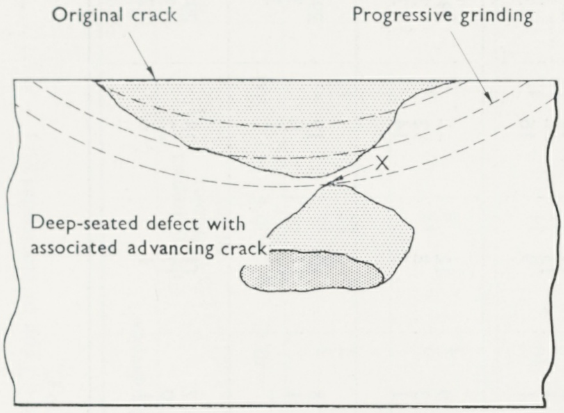
This will almost certainly require repeated magnafluxing and chipping and grinding, and in fact implies a close cooperation between these departments.

The foregoing words are so important that no apology is made for drawing special attention to them.

Sooner or later the Surveyor will meet a foundry inspection official suffering from an acute attack of "delivery datitis", who will be most persuasive in the argument that fine indications revealed by magnaflux at the bottom of a chipped or ground-out zone can safely be "lost" by welding over them.

The Surveyor will do well to pause and consider!

It is quite possible that the original flaw has been progressively pursued down from the surface of the material and the so-called "residual micro-crack" appearing at the bottom of the ground-out zone may well be the first indication of a deep-seated and much more serious defect (Fig. 4).



X Position of supposed "residual micro-crack"

Fig. 4

If the Specification or Code to which he is working only calls for magnaflux he should not release any area for repair welding until he is satisfied that magnaflux, properly applied, is 100 per cent negative.

It should also be borne in mind that "final" magnaflux testing should be applied after all heat-treatment has been completed.

The method of gouging which employs a carbon electrode, together with a parallel jet of compressed air for blowing clear the molten metal and slag, is very attractive for its speed and efficiency in the hands of a trained operator working on normal carbon steels, but on 13 % chromium steel it is seldom, if ever, used; chipping and grinding are preferred on areas which will operate under high stress.

Ideal conditions exist in the foundry for the weld repairs of defects—full use can be made of furnaces, induction heating, etc., and in order to avoid unnecessary repetition, the principles which apply are dealt with in detail under the heading "Repairs at the Power Stations".

Elsewhere in this paper considerable emphasis is laid on the importance of employing electrodes of suitable composition when welding 13 % chromium steel.

Welding engineers live with this matter and welding shop managers are sure to be familiar with the subject, but the Surveyor who goes home at night with an easy mind is the one who knows without any doubt that the *foremen* in his district (who are so much closer to the seemingly mundane matters of electrode selection and distribution) also fully understand the vital importance of this point.

It is therefore recommended that the Surveyor keeps in contact with the men on the floor of the shop. (This can also be most rewarding when one wishes to assimilate the local horticultural knowledge which is absolutely essential when starting a garden in a foreign land with unfamiliar climatic variations!)

It is always useful to arrange a visit to coincide with the welding work so that the opportunity can be taken to examine the label on the packet from which the welder is extracting his electrodes. By this means the Surveyor can readily satisfy himself that the "Rod for the Job" is being used.

GENERAL REMARKS

(a) The Rod for the Job

The importance of selecting *suitable electrodes* when welding alloy steels cannot be over-emphasised, and from the cases which are referred to below it will be evident that this point is not always fully appreciated by those in charge of such work.

It is understood that this advice is given when the turbines are handed over, but it can be appreciated that after twelve or more months of concentrating on all the diverse problems associated with the operation and management of a large power station the Superintendent (who is unlikely to be a trained welding engineer) when suddenly faced with some incipient cavitation or damage from solid matter, is liable to institute immediate repairs consisting of building-up the affected areas with weld metal followed by smooth grinding. It is by no means likely that the man behind the welder's mask is any better informed on this subject, and all those concerned are probably quite happy when the "repaired" runner is finally lowered into place and put back into service.

Imagine the surprise when after two thousand hours of running with water at a pressure of, say 70 kg/sq.cm. striking these welded zones, conditions are found to be much worse than they were before. Now cracks are evident, and if he is wise the Superintendent will lose no time in seeking expert advice, otherwise he is sure to add to his burden of misery!

The solution of this problem may be for a large power-producing concern operating a number of stations to establish a central repair depot with fully qualified personnel properly equipped, and capable of providing an efficient and reliable maintenance service for these alloy steel castings under controlled conditions.

At the time of writing (Spring 1963) the dangers of casual welding on such castings have been recognised, and welders from the power station maintenance departments are receiving training in the workshops of the supplying engineering contractors, and highly qualified welding engineers are arranging demonstrations of correct techniques in the power station repair shops for the welders, and are giving more detailed supplementary lectures to the Superintending Staff.

A striking example of the result of welding 13 % chromium steel with unsuitable electrodes is well illustrated in Fig. 5.

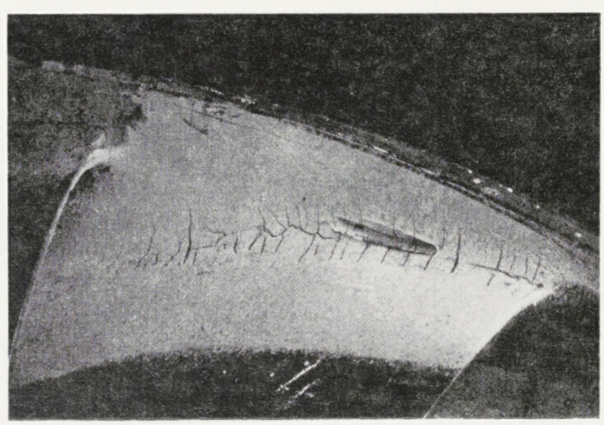


Fig. 5

Crack detection by dye-penetrant method on fillet between vane and skirt of a Francis runner in 13 % chromium steel

Table III.—Test Results of Weldments. Base material: 13 % chromium steel; Type of electrodes: 13 % chromium

Heat Treatment			Mechanical Properties							Fatigue Strength	
Preheating	Stress Relieving		Y.P. kg/mm²	U.T.S. kg/mm²	Elong. L=5d %	Red. of Area %	Charpy Impact (keyhole) kgm/cm² −40°C	+20°C	+100°C	push-pull ±kg/mm² 10 million cycles unnotched	notched r=0·12 mm
200°C	—	Base Material	42	66	15	73	8	13	—	29–30	14–17
		Transition zone	—	—	—	—	1	6	5	30	16
		Weld deposit	58	88	8	35	—	2	5	31	14
200°C	680°C 12 h	Base Material	47	65	25	68	8	12	—	29–30	14–17
		Transition zone	—	—	—	—	14	—	22	28	12
		Weld deposit	40	69	11	55	1	10	14	30	16
400°C	—	Base Material	53	67	12	58	2	10	15	29–30	14–17
		Transition zone	—	—	—	—	1	13	—	32	13
		Weld deposit	72	100	4	20	1	9	16	35	17
400°C	680°C 12 h	Base Material	42	67	21	64	9	12	—	29–30	14–17
		Transition zone	—	—	—	—	3	8	12	31	12
		Weld deposit	50	72	14	51	1	5	14	30	12
600°C	—	Base Material	49	65	26	72	8	10	19	29–30	14–17
		Transition zone	—	—	—	—	1	—	6	33	15
		Weld deposit	75	95	4	11	—	1	1	35	20
600°C	680°C 12 h	Base Material	49	64	23	73	7	11	18	29–30	14–17
		Transition zone	—	—	—	—	10	17	22	30	17
		Weld deposit	43	60	17	64	1	1	6	26	18

Table IV.—Test Results of Weldments. Base material: 13 % chromium steel; Type of electrodes: austenitic and austeno-ferritic; Preheating temperature 150° C.

Type of Electrodes	Location of Test Bars	Heat Treatment after Welding	Mechanical Properties						Fatigue Strength push-pull ±kg/mm² 10 million cycles
			Y.P. kg/mm²	U.T.S. kg/mm²	Elong. L=5d %	Charpy Impact (keyhole) kg/cm²			
						−40°C	+20°C	+100°C	
Austenitic 18 Cr/8 Ni	Weld deposit	—	33	55	50	5	10	12	24
	Transition zone		39	58	21	7	13	18	24
	Weld deposit	680°C/12 h	33	59	13	7	13	18	29
	Transition zone		29	59	12	4	5	6	26
Austenitic 25 Cr/20 Ni	Weld deposit	—	33	55	24	10	11	12	14
	Transition zone		33	52	16	8	15	10	17
	Weld deposit	680°C/12 h	28	56	13	7	8	8	17
	Transition zone		38	61	12	6	10	8	17
Austenitic high-manganese 18 Cr/8 Ni/6·5 Mn	Weld deposit	—	26	51	18	10	13	21	22
	Transition zone		31	56	21	10	10	21	26
	Weld deposit	680°C/12 h	29	61	13	7	16	21	23
	Transition zone		31	62	13	14	19	23	26
Austeno-ferritic 27 Cr/8 Ni	Weld deposit	—	67	80	15	1	3	5	28
	Transition zone		67	73	18	4	8	10	28
	Weld deposit	680°C/12 h	43	61	0·7	—	0·5	10	21
	Transition zone		57	67	0·8	0·5	2	4	22
13% chromium steel in comparison		heat treated	45	65	15	—	4	—	29

In this case, severe cracks were found in the fillets of a Francis runner. The parent metal was 13 % chromium steel and it was established by analysis that a previous weld repair had been made using electrodes of 18 per cent Cr., 8 per cent Ni. composition.

This runner is still operating successfully seven years after having been properly repaired under controlled conditions.

It is now necessary to devote attention to the results of extensive tests carried out by the laboratory staff of one of the foundries here in order that the foregoing failures can be properly understood.

Table III shows the effect on the mechanical properties when 13 % chromium steel base metal is welded with 13 % chromium steel electrodes with different pre-heat and stress-relief treatments.

Table IV gives the test results obtained by welding 13 % chromium steel base metal with a variety of electrode compositions, with and without welding heat-treatment.

A study of these tables will show that when welding 13 % chromium base metal with a 13 % chromium electrode the best mechanical properties are obtained when pre-heat does not exceed 400° C. followed by stress-relieving at 680° C. for 12 hours.

As an example of what will result from the welding of 13 % chomium steel base metal with an electrode of 27 per cent Cr. 8 per cent Ni. followed by heat treatment after welding the following results are extracted from Table IV: Y.P. 43 kg./sq. mm., U.T.S. 61 kg./sq. mm., E per cent on 5d 0·7; Charpy at +20° C. 0·5 kg./sq. cm.; fatigue strength push pull ± kg./sq. mm. (10 million cycles) 21.

In other words, although the yield and U.T.S. values remain high, the elongation and impact strength are hopelessly low and the fatigue strength is also impaired, all of which indicate that serious cracking is sure to arise in such welds.

It will be noted that this effect only occurs when the deposited weld metal is subsequently heat-treated; but it should be borne in mind that it is quite usual in the case of turbine runners subject to heavy wear in service to return them from time to time to the steel foundry or to the turbine manufacturer for complete overhaul by welding of the eroded or cavitated areas, and subsequent stress-relieving in the furnace.

Should austenitic or austeno-ferritic electrodes have been used earlier, these welded zones will become embrittled with disastrous results.

(b) Non-Destructive Testing and Preparation for Repair

When water turbines are opened up for routine inspection they should be checked by magnaflux over the stressed zones and in way of any previous welded repairs. (The latter point implies the keeping of accurate records of all welding work carried out on the runners.)

Convenient portable magnaflux units are available for this purpose and have adequate sensitivity using magnetic "ink", i.e. the magnetic particles are suspended in a suitable fluid which is applied by a small hand sprayer (Fig. 6).

Little more need be added here other than to repeat the advice given in the section dealing with the production of the castings—when a defect is found by magnaflux, rewelding should never be contemplated until all indications have been removed.

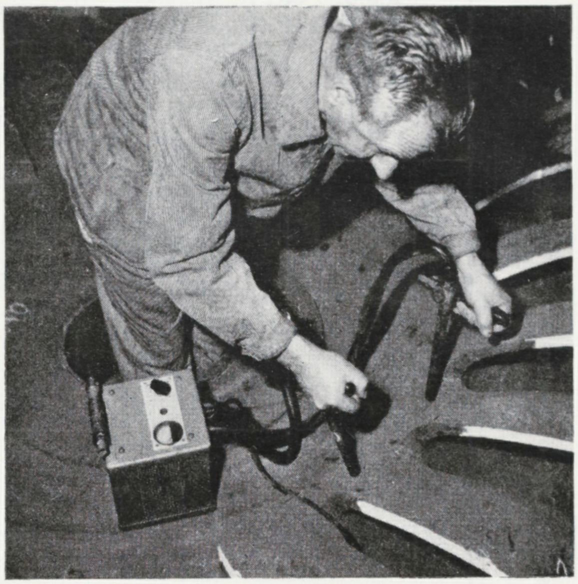


Fig. 6

Lightweight portable magnetic crack-detection equipment passing a current of 1,000 amps.—frequently used in the power stations

(c) Pre-Heating

For pre-heating for site repairs at the power stations propane or butane gas burners are used (Fig. 7), and these can also be employed to stress-relieve the welds locally.

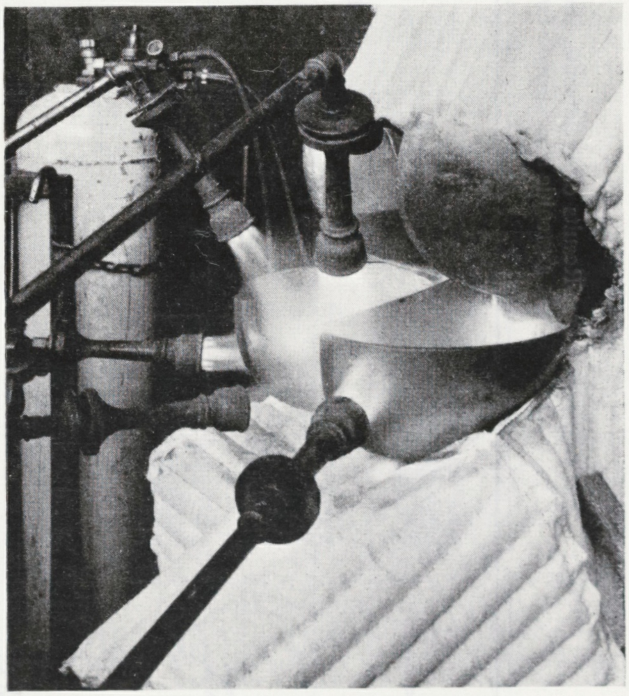


Fig. 7

Pre-heating a Pelton wheel bucket by propane gas torches at a power station

During pre-heating it is important to ensure that the centre of a Pelton bucket or a Kaplan blade is not heated excessively, otherwise heat concentration and subsequent stresses in the material are provoked.

It is recommended that the heat be applied from the outer edges as indicated in Fig. 8 in order to permit of expansion of the material.

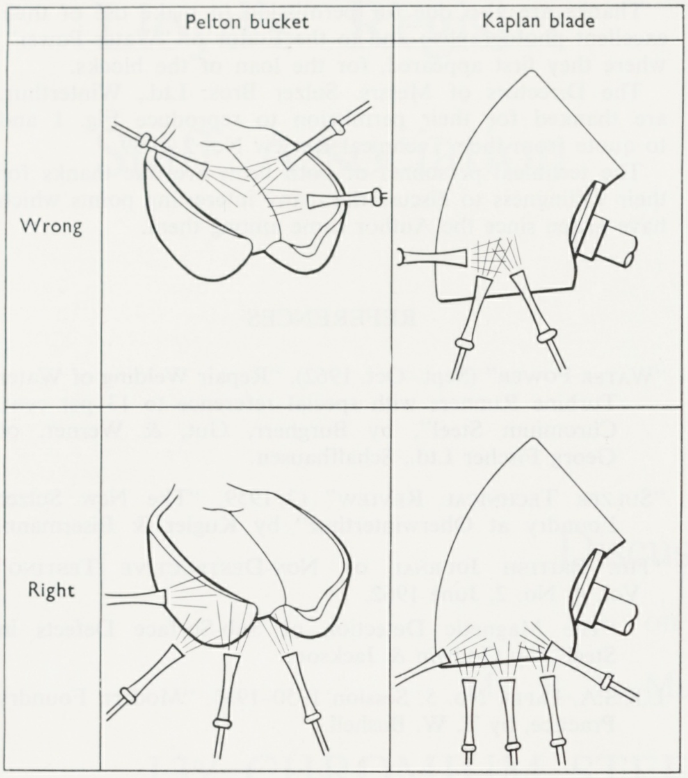


FIG. 8

Correct and incorrect pre-heating of Pelton buckets and Kaplan blades

(d) TEMPERATURE CONTROL

The ultimate success of repairs by welding depends to a very great extent on strict adherence to the recommended temperatures at the various stages of the operation.

Sensitive instruments are available in the foundries which give excellent results, but in the "field"—(often a great Aladdin's cave deep in the heart of a mountain!)—satisfactory repairs are regularly controlled by the use of the well-known temperature-indicating crayons (tempilsticks) in the hands of personnel experienced in their application.

(e) ELECTRODES

Much of this paper has been devoted to the importance of recognising that suitable electrodes should be used when welding 13 % chromium steel castings and the dismal results to be expected when this precaution is neglected.

It may not be out of place to state here that the basic coated electrodes should be baked for four to six hours at about 250° C. in a drying oven prior to use, and no Surveyor should show surprise if from time to time he finds a tasty sausage in the same oven! He will draw satisfaction from the knowledge that a well-fed welder with no domestic problems is the one most likely to produce acceptable welding.

The diameter of the electrodes must be carefully selected to avoid excessive heat input on the base material, and it is recommended that rods of 2·5 mm. to a maximum of 4 mm. be employed.

(f) STRESS-RELIEVING

The reasoning which was applied to the method of pre-heating is also employed in stress-relieving after repairs by welding, where the highest temperature should be attained at the outer extremity with the temperature gradient falling inwards (Fig. 9).

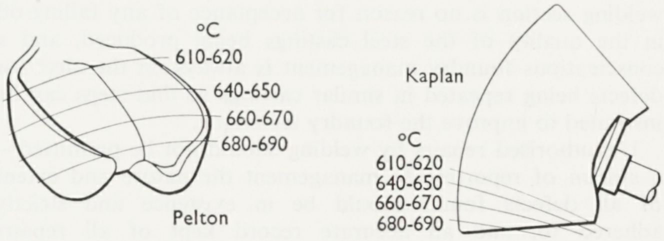


FIG. 9

Temperature distribution for local stress relieving (Pelton and Kaplan)

A satisfactory method of local stress-relieving Pelton wheel buckets after welding repairs to the roots in a power station is shown in Fig. 10.

Twelve gas torches are applied and regulated so as to give the required temperature gradient. Attention is drawn to the simultaneous heating of the adjacent buckets to minimise heat-induced stresses, and to the generous application of asbestos matting.

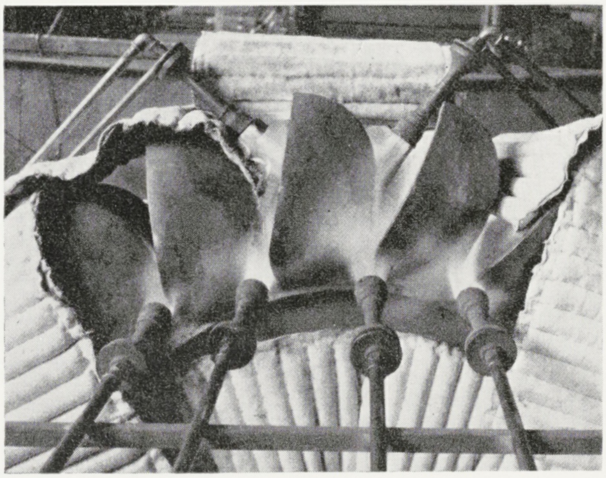


FIG. 10

Local stress relieving of weld repair of root cracks on two buckets of a Pelton runner

(g) HEAT-TREATMENT TEMPERATURES

An appreciation of the metallurgical properties of the material being welded and heat-treated is necessary if complete success is to follow repairs by welding.

Whereas temperatures of 700–720° C. eliminate the stresses induced by welding, the mechanical properties of the 13 % chromium steel would be reduced to 55–60 kg./sq. mm. ultimate tensile strength, and 35–45 kg./sq. mm. yield point.

On the other hand, at a temperature of 600–640° C. neither welding stresses nor the high hardness in transition zones will be sufficiently reduced.

Correct pre-heating temperatures for the material under notice are in the range 250–400° C., and correct stress relieving will be effected between 650 and 700° C.

CONCLUDING REMARKS

The fact that a steel foundry is equipped with a complete welding section is no reason for acceptance of any falling-off in the quality of the steel castings being produced, and a conscientious foundry management is always on the alert for defects being repeated in similar castings so that steps can be instituted to improve the foundry technique.

Unauthorised repairs by welding should not be permitted—a system of reporting to management the nature and extent of all defects found should be in existence and strictly adhered to, and an accurate record kept of all repairs effected. The Surveyors should be fully informed at all stages.

Repairs by welding carried out in zones known by experience to be important should be subjected to radiographic or ultrasonic testing. On completion of all welding, castings should receive the appropriate heat treatment, followed by magnetic crack detection of all repaired areas in the smooth ground condition.

Only experienced welders should be employed on this work using well-maintained equipment and following standardised procedures laid down by the welding engineer in charge.

Strict supervision of the issue and application of electrodes is essential.

ACKNOWLEDGMENTS

The Author is indebted to the Directors of Messrs. Georg Fischer Ltd., Schaffhausen, for permission to reproduce Tables I, II, III and IV which are the outcome of a long series of tests conducted in their research laboratories and which first appeared in "Water Power" in the Autumn of 1962.

Thanks are also due for permission to make use of their excellent photographs; and to the Editor of "Water Power", where they first appeared, for the loan of the blocks.

The Directors of Messrs. Sulzer Bros. Ltd., Winterthur, are thanked for their permission to reproduce Fig. 1 and to quote from their Technical Review No. 2/1959.

The technical personnel of both firms are due thanks for their willingness to discuss the many interesting points which have arisen since the Author came among them.

REFERENCES

"WATER POWER" (Sept.–Oct. 1962). "Repair Welding of Water Turbine Runners with special reference to 13 per cent. Chromium Steel", by Burgherr, Gut, & Werner, of Georg Fischer Ltd., Schaffhausen.

"SULZER TECHNICAL REVIEW" (2/1959. "The New Sulzer Foundry at Oberwinterthur" by Kugler & Eisermann.

"THE BRITISH JOURNAL OF NON-DESTRUCTIVE TESTING" Vol. 4, No. 2, June 1962.

"The Magnetic Detection of Sub-Surface Defects in Steel", by Godwin & Jackson.

L.R.S.A. PAPER No. 5. Session 1950–1951. "Modern Foundry Practice, by T. W. Bushell.

PRINTED BY LLOYD'S REGISTER OF SHIPPING AT GARRETT HOUSE, MANOR ROYAL CRAWLEY, SUSSEX, ENGLAND

Lloyd's Register
Staff Association

Session 1964-65
Paper No. 1

Discussion

on

Mr. R. F. Munro's Paper

13% CHROMIUM STEEL WATER TURBINE CASTINGS IN SWITZERLAND AND THEIR REPAIR BY WELDING

LLOYD'S REGISTER OF SHIPPING

71, Fenchurch Street, LONDON, E.C.3

Discussion on Mr. R. F. Munro's Paper

13% CHROMIUM STEEL WATER TURBINE CASTINGS IN SWITZERLAND AND THEIR REPAIR BY WELDING

Mr. G. P. SMEDLEY

Mr. Munro has presented a useful paper on the repair by arc welding of large castings of 13 per cent chromium steel. He shows that such steel is not difficult to repair efficiently providing certain precautions are taken.

I agree that care must be taken to make sure that welds are only deposited on sound metal. The removal of defects should certainly be completed by chipping and grinding. Arc-air gouging is undesirable due to the high heat input and carbon pick-up by the steel. Unless there is strict control local areas of the gouged surface can be so high in carbon as to resemble a white iron. Failure to remove the carburised layer by careful and thorough grinding will most probably result in underbead cracking and will certainly create a very hard zone. There is no simple check which can be made to prove that none of the carbon-rich layer remains.

The stainless steel under consideration is of martensitic type. Preheating of the casting is essential before welding and the preheat temperature should be maintained until welding is completed and stress relief heat treatment is commenced. Quoted preheat temperatures vary from about 200° C. to 400° C. The actual temperature depends on the hardening characteristics of the cast steel and the intended service. A temperature of 250° C. is often preferred. The reason is that when higher preheat temperatures are employed, it is desirable to cool after welding to 175° C. to 200° C. This permits the main of the austenite in the weld to transform.

Most castings are air hardened and tempered. In general, the temperature for stress relief heat treatment should not exceed the tempering temperature. Stress relieving at 680° C. for one hour/inch of thickness is suitable when a previous tempering temperature of 700° C. was used. 680° C. is usually regarded as the minimum for stress relief heat treatment of 13 per cent chromium steel. In general, both the tempering and stress relieving temperatures are at least 20° C. higher.

It is now fairly well known that the alloy content of the welding electrode should be in the rod and not, in part, in the coating. Also a short arc must be used during welding to minimise the loss of chromium and to achieve adequate heat input. The slag formed on 13 per cent chromium weld beads can be firm and difficult to remove. Special care should be taken to see that it is removed from the surfaces of weld beads, between runs.

Although some sound welds can be made with austenitic steel rods, these are not as reliable as deposits made with matching electrodes. Austenitic steel weld deposits should only be preferred for relatively thin sections where preheating is impractical and service does not involve either corrosive conditions or elevated or cyclic temperatures.

With reference to local flame preheating and post-welding heat treatment, the precautions which should be taken are not entirely clear from Fig. 8 and the text. Moreover, Fig. 8 does not appear to line up with Fig. 7. The important points to observe are (1) steep temperature gradients should not occur either through the metal thickness, or along the section. That is, heat must be applied fairly slowly and preferably to both upper and lower surfaces. It should not be too concentrated. (2) On a curved surface the heat input is to be less on one surface and it should be on the concave surface. (3) Free edges which may absorb heat rapidly should be shielded from the flame or should be kept out of the direct path of the flame.

Pelton wheels in particular are subjected to impact loading during service and run at high speeds. The steel should be tough. I can recall at least one case where cast 13 per cent chromium steel buckets of a built type runner, fractured during service. The steel had relatively poor V-notched bar impact properties. Could Mr. Munro state why a lower impact criterion is applied to 13 per cent chromium steel than to carbon or low alloy steel Pelton wheels castings (*see* Table I). I should be interested to know the temperature at which the impact tests are made and if there is any reason for the preference of the keyhole test piece over the standard V-notch type?

Mr. R. E. LISMER

I must congratulate Mr. Munro on giving us a very interesting paper and, even if the subject seems highly specialised, the precautions and information on inspection procedure are well set out and serve as very important guidance to other Surveyors.

Examination of equilibrium and transformation diagrams will show that the composition of this quality of steel is very critical. There are quite a number of types of stainless steels in which the critical importance of small composition variations have to be appreciated. The addition of 13 per cent chromium happens to be maximum for corrosion consideration compatible with the ability to heat treat and obtain high strength in large sections. This type of steel is actually known as "stainless iron" and was developed in Sheffield shortly after the First World War.

Carbon was and is always the "bogy" element for stainless steels, and when the manufacture of a low carbon grade of ferro-chromium was at last achieved, Brearley in his researches with straight chromium steels was the first to demonstrate that improved ductility and impact strength could be attained in the low carbon alloy. Nowadays, the low carbon content is desirable for ease of welding. In fact, the 13 per cent chromium steel is being developed as a high strength stainless structural quality.

The composition is just within the fully transformable alloy range and however we cool from the solution temperature, the structure will be martensite. It is very difficult to soften the steel for machining. Details of the heat treatment are given by Mr. Munro, but these should be defined as a solution treatment at 1050° C. to completely dissolve the carbides and an annealing at 700° C. for easy machining, that being the highest temperature which does not produce re-austenisation. The essential consideration for the maximum benefit from heat treatment, is for the steel to be ferrite-free at the solution temperature. Any ferrite present at this temperature will reduce the tensile strength and proof stress of the steel and

detract from the impact resistance. The possibilities of adding alloying elements to further improve the mechanical properties of the 13 per cent chromium steel are based on their ability to improve the tempering resistance without forming ferrite during solution treatment.

Mr. Munro has indicated the critical conditions of casting high chromium steels. They must be poured very hot because of the sluggish characteristics of the liquid metal. They thus have severe chemical and erosion effects on the refractory moulding materials and chromium forms its own brand of refractory-type inclusions. In the intricacies of the nature of Francis runners or Pelton wheels, the inclusions become unable to be carried towards the gate headers and can be trapped in the fillets of the blades, especially on the underfaces. Porosity and chromite inclusions segregates form adjacent to the headers.

Similar difficulties in the manufacture of such very large Francis runners arose under the surveyance of the Sheffield office nearly 12 years ago. These runners were intended for the hydro-electric schemes in Tasmania and the work was closely followed by Dr. Dorey. Speed for completion of the project was all important. Not-too-good quality castings had to be repaired by welding and installed by a certain time. Seasonal conditions in Tasmania meant that their service would be extremely severe and thus the nature of the weld repairs to the castings was an important feature of the Surveyor's duty. Radiography revealed the massive extent of the segregated areas and cut-outs up to 6 in. deep were requested. The positioning of the X-ray films on the complex shapes adjacent to the blades provided difficulties and the interpretation of the results by the Surveyors needed very great care.

Also, some of the blades had to be deliberately cut because their shape and location were not true enough. They were hammered into correct position and welded along the fillets. Because of the lack of accessibility for welding between the blades, considerable thought had to given to the welding procedure.

With the major repairs, the cut-outs were proved free from permanent defect, because satisfactory deposition of a high-alloyed weld metal cannot be made on unsound cast metal of this quality. Radiographs were requested after chipping and grinding before any welding was started.

If a weld of 18/8 or straight 13 per cent chromium composition was deposited on the casting, then cracking of the type shown in Fig. 5 of Mr. Munro's paper was likely to occur. Thus, in the first instance, the surface of the cut-out was buttered with a 25/30 composition and this was followed by a stabilised 18/8 filler deposit. The surfaces were then ground and radiography repeated to prove freedom from defects. Pre-heat was at 250° C. and provided by gas ring type of heaters. Stress relief after welding was at 650° C.

The 25/20 deposit being fully austenitic would retain the hydrogen in solution and thus avoid cracking in the heat affected zone. The use of an 18/8 electrode direct on the 13 per cent chromium parent material would give a austenite-ferrite structure and thus produce the hydrogen type of cracking shown by Mr. Munro.

This work was carried out in Sheffield in January, 1953, and the procedure was within the present recommendations by Mr. Munro. All the weld repairs were carefully wrapped and identified, so that they could be assessed with any subsequent failure in service. No failures have been reported and the Sheffield office successfully completed a difficult survey.

To conclude, I would like to ask Mr. Munro to define the nature of the defects which required weld repairs and how the variables in casting techniques affected their occurrence.

Mr. Boyd

I agree with Mr. Smedley's remarks about impact tests, Tables III and IV. The V-notch test is more discriminating and easier to interpret.

It is difficult to say what interpretation can be put on the impact data in these Tables, particularly as the "transition zone" is not defined. Presumably the notches were in the "transformed" zone, but it is known, at any rate for carbon-manganese steels, that the main embrittlement occurs in the heat affected zone beyond the transformed zone.

On page 8 the term "Impact Strength" is used. This is a misnomer, since strength has the dimensions of force, whereas impact values have the dimensions of energy. The term is also misleading since it suggests that notch toughness is proportional to impact energy, which is not so. The impact tests should be interpreted as indicating the transition range, and this is not evident from the values given.

Finally, "If one may repair Pelton runners by welding, why not crankshafts?"

Mr. J. Wormald

The title given to this paper cannot fail to create the impression in some minds that it is a highly technical paper on a specialised subject whereas it is welding wisdom presented with understanding of a Surveyor's difficulties and illustrated by examples from a branch of the subject to which the Author has had unlimited access. It is to be hoped that nobody has been frightened by the title.

Few of us will be in a position to comment on the water turbine aspects of the paper but they, in effect, provide the continuity and an interesting background to an exposition of the problems encountered when welding is employed as a means of repair of alloy steel castings in general.

At the top of page 5, Mr. Munro advises us to pursue a surface crack beyond the "residual micro-crack" and then draws attention to a deep-seated defect with associated advancing crack. Would it be unfair, or superfluous, to ask what would have happened if there had not been a surface crack?

In the section headed "The rod for the job", Mr. Munro comments on the results of tests carried out on specimens which had been heat treated after welding and he points out that the elongation, impact strength and fatigue strength of certain weldments had been seriously impaired by heat treatment which followed the use of unsuitable electrodes. Many of us have been led to believe that stress relieving after welding can do no harm, even if it does no good, but my interpretation of Mr. Munro's argument is that stress relieving, or any other form of heat treatment, can aggravate an unfavourable condition created originally by the use of unsuitable electrodes. Would Mr. Munro care to expand on his argument with relation to alloy steel castings generally?

The two final paragraphs of this section lead to the conclusion that it can be dangerous to heat treat an alloy steel casting without consulting a "case-card" covering the whole of its past history. Is this a correct evaluation of what has been written?

Mr. Munro's remarks about welders being experienced in the class of work on which they are engaged, and about well-fed welders with no domestic problems or other distractions, brings home the fact that no matter how good the tools of the trade may be, a Surveyor is called upon to inspect and accept responsibility for work whose reliability depends very largely on the mental approach of the operator to his task.

There is a wealth of information, often couched in characteristic asides, in this paper and Mr. Munro deserves our thanks and congratulations for having presented the Staff Association with an interesting and valuable contribution.

AUTHOR'S REPLY

To Mr. Smedley

I am particularly grateful to Mr. Smedley for his contribution not only because of the detailed points he has taken up and clarified but because of his general acceptance of the fact that 13 per cent chromium steel is not difficult to repair efficiently provided certain precautions are taken.

Mr. Smedley's remarks on arc-air gouging are particularly welcome because this is a matter that has been giving me considerable concern. The whole basis of the lack of confidence in this method of removal of material is indeed the fact that there is no simple check which can be made to prove that none of the carbon-rich layer remains, and that therefore in the uncontrolled conditions obtaining in this method the dangers of under-bead cracking are very real indeed. Should the operator allow the carbon electrode to touch the surface being gouged the transfer of carbon will be enormous.

To obtain crack-free repairs on 13 per cent chromium steel a pre-heating of the area to be welded is, of course, necessary. Its purpose is to have the base material above the martensitic transformation temperature (about 250° C.) during welding. The pre-heating temperature depends in the first instance on the extent and position of the cut-out zone to be welded, and Mr. Smedley's exposition of the reasons for this temperature are appreciated. His further comments that a short-arc must be used during welding to minimise the loss of chromium and to achieve adequate heat input, and his remarks on the removal of the slag from 13 per cent chromium welding are confirmation that the welders engaged on this work must be fully conversant with their duties.

I am grateful to Mr. Smedley for drawing attention to the misinterpretation which could be placed upon Fig. 8 and the associated text in connection with local flame pre-heating and post-weld heat-treatment. This matter was of course put right at the presentation of the paper when I said that the photographs and sketches show the positions of the various burners at a particular instant in time, and that to represent this process adequately on film it would be necessary to use movie. The burners are in fact constantly being moved about following precisely the principles laid down by Mr. Smedley in this connection.

Mr. Smedley draws attention to the impact loading and high operating speeds of Pelton runners and recalls at least one case where 13 per cent chromium steel buckets of a built type runner fractured during service due, presumably, to relatively poor V-notched bar impact properties. This serves to emphasise the earnest nature of the inspection of such castings because, due to the very fine scantlings employed for the Pelton turbine casings a fractured bucket could well prove dangerous to life.

I am in turn reminded of a 13 per cent Cr. Pelton runner of the integral cast type which suffered the loss of a bucket while running under load, due to the impact of a jet needle which failed for reasons with which we are not concerned here. The point I wish to bring out is that on receipt of the damaged runner the steel foundry was able to cast a new bucket, and attach it to the hub by means of welding, following the general procedure outlined in the paper, using matching electrodes. There is no doubt that this constituted a major repair, and so far as I am aware this turbine is still giving satisfactory service.

The Charpy (keyhole) impact figures quoted in Table II were obtained at room temperature.

It is interesting to note that our metallurgists have queried the use of the keyhole test piece in preference to the Charpy V-notch type which has been described as more discriminating and easier to interpret. This underlines the urgent need for international unification of this type of test; a glance at page 455 of the 1965 Rules being sufficient to show how complex this matter has become.

I understand that the Swiss are represented on the International Committee which is charged with attempting to achieve parity in this direction, and we can only hope that these various gentlemen can soon agree upon an internationally acceptable standard impact test piece.

The figures given in Table II are minimum guaranteed values, and in view of the higher tensile properties of 13 per cent chromium steel a lower impact value must be expected, however, an analysis of a large number of actual results obtained from cast-on test bars shows that for a plain carbon steel of 45 Kg./mm.^{2} U.T.S. an impact result of between 10 and 16 MKg./cm.^{2} (VSM) can be obtained at room temperature, and comparable impact figures from 13 per cent chromium steel with a minimum U.T.S. of 65 Kg./mm.^{2} fall between 8 and 16 MKg./cm.^{2} (VSM) at room temperature The reason for the rather close similarity in the actual impact results obtained despite the higher tensile value of the chromium steel, is that, due to the high alloy content, a martensitic structure is obtained by normalising and on subsequent tempering this gives optimum notch toughness associated with high tensile strength.

To Mr. Lismer

I am grateful to Mr. Lismer for his history and description of 13 per cent chromium steel and his treatment of the metallurgical principles of this alloy, which is a valuable addition to the paper.

The detailed description given by Mr. Lismer of the extensive repairs by welding effected to large 13 per cent chromium steel cast Francis runners in the Sheffield area in January, 1953, is most interesting, and the Sheffield office should be congratulated on a difficult job well done.

I cannot completely agree with Mr. Lismer's statement that if a weld of 18/8 or straight 13 per cent chromium composition was deposited on a 13 per cent chromium base material cracking was likely to occur, but accept that 13 years ago it is likely that much more carbon was present in the base material that is the practice to-day.

At the present time such a major repair as that described by Mr. Lismer would certainly be carried out with 13 per cent chromium electrodes and the employment of 18 Cr./8 Ni. laid on a buttering layer of 25 Cr./20 Ni. composition would not be contemplated.

In the decade which has elapsed since the Tasmanian runners were repaired great developments have taken place, and we now have Francis runners operating at water heads and consequent stresses which would have been considered the sole preserve of the Pelton type of turbine ten years ago.

The is nothing wrong with the employment of 18 Cr./8 Ni. and 25 Cr./20 Ni. composition electrodes on 13 per cent chromium runners provided their use is confined to unstressed or low-stressed zones, and provided that subsequent heat treatment will not be required. These electrodes are attractive at first sight because, due to their high ductility, the tendency to weld cracking is reduced, and the deposited metal displays good resistance to cavitation and erosion, but it should not be overlooked that while pre-heating of the 13 per cent chromium base material to 150°–250° C. is recommended, local stress relieving heat treatment at 650° C., or stress relieving of the whole runner casting at any time in its subsequent life should not be carried out for the reasons already given in the paper, and this latter restriction is virtually intolerable.

It is the duty of a responsible engineer to seek the best mechanical properties obtainable for the known or expected service conditions to be encountered, and when faced with the alternative of scrapping a costly casting or deciding upon a reliable weld repair procedure for defects found in highly stressed zones it is necessary to carefully consider and balance all the relevant factors:—
Yield, U.T.S., Elongation, Impact and especially Fatigue.

A simple summary of what has already been presented is as follows:—

BASE MATERIAL 13 PER CENT CHROMIUM. Preheat temp. 150° C.–heat treated 680° C./12 hours.

Electrodes	Y.P. Kg./mm.²	U.T.S. Kg./mm.²	Elong. L=5d %	Impact MKg./cm.² Charpy Keyhole (R.T.)	Fatigue ± Kg./mm²
Minimum values 13% Cr.	45	65	15	4	29
Actual measured values 18 Cr./8 Ni	29	59	12	5	26
25 Cr./20 Ni	38	61	12	10	17
27 Cr./8 Ni	57	67	0·8	2	22

and it requires but little study of this Table to appreciate that the most satisfactory results are to be expected from the employment of matching electrodes.

Mr. Lismer asks for my definition of the nature of defects which require repair by welding, and goes on to ask how the variables in casting technique affect their occurrence. In reply to the first part of this question I must firstly say that much depends upon the nature and location of the defect. A fundamental and most important issue is raised in this question and it is reflected in the foreword to the paper, in which I implied that the perfect steel casting has not yet been poured.

There is no simple answer to the question. Of course, cracks found on the surface of castings by magnetic particle inspection are chipped or ground out, proved clear and the zones re-welded. Of course, shrinkages located by ultrasonics in stressed zones of Francis runners are excavated and welded up after observing all the standard precautions, and, of course, dangerous defects located by radiography in the bucket roots of Pelton runners are dealt with similarly. The foregoing defects all affect the ultimate reliability of the castings in service, but in certain circumstances even fine porosity on the surface of the casting is unacceptable. This is the bogy which usually comes to light at the finished-grinding and polishing of the casting at the turbine manufacturer's works and gives rise to seemingly endless discussions between him and his steel founder. Patches of fine porosity exposed on the finished ground surfaces of Pelton buckets can, with safety, be left for a few thousand hours of service before deciding if repair is really necessary.

The station engineer can soon judge by close observation which runners are cavitating, and which are showing excessive pitting in way of original fine porosity. In many cases normal erosion removes the doubtful surface to the satisfaction of all concerned, and a reasonable time in service should be allowed before insisting on weld repairs of seemingly minor pores revealed at the final stage of manufacture. In this connection it should be remarked that the examination of Pelton runners at the power station is a relatively simple operation, requiring little time out of service.

Much thought has been devoted to the drawing up of standards and to the classification of castings in terms of service conditions, and of defects in terms of "acceptable", "borderline", and "away with them!" While this approach to the problem has much to commend it, since with its standard radiograph comparators, etc., differences of opinion between interested parties can be readily resolved, the Society prefers to adhere to the time-honoured phrase, "each case to be considered on its merits", and that brings us back to what I have just written about the nature and location of the defect which, in my opinion, is the more practical approach. When faced with making a decision about weld repairs the Surveyor must bring to bear his own knowledge of the service conditions of the zones in question and relate thereto his interpretation of the information about the defect given to him by the non-destructive methods available.

It is easy for a Surveyor to call for the removal of all defects wherever they may be found and regardless of their nature, and by consistently following this policy of 100 per cent-ism he will very soon cause a financial crisis in his steel foundry. In the current conditions of keen competition which exist in the steel casting business ultimate production costs and delivery dates are assuming more and more importance and there is a growing tendency in the foundries to cast a highly critical eye over client's specifications. For example, if a customer calls for 100 per cent radiography of his casting he will be asked to pay a certain sum as cost for the films, and probably a very considerable surcharge to cover the foundry for the *risk* of repairs which may be found necessary as the result of the radiography.

It should not be concluded from the foregoing that I advocate a general lowering of inspection standards. I simply wish to emphasise that both purchasers and the Surveyors charged with the inspection of 13 per cent chromium steel castings should recognise that while a steel foundry can despatch to site a casting perfect in all respects, great judgment and experience must be brought to bear in accepting a highly-stressed water turbine casting which is completely adequate for its purpose and will prove reliable in service without a rigid insistance on the removal of all defects regardless of where they may be located. Of course, in many

instances the Surveyor is not free to exercise his initiative in such matters but must adhere strictly to the terms of the client's specification.

Under the concluding remarks in the paper I mentioned that good foundry management is constantly on the alert for recurring defects which indicate that the casting techniques should, if possible, be improved, and one large foundry here employs an experienced photographer in the non-destructive testing department whose duty it is to despatch photographs to the moulding shop manager which clearly show the exact position and extent of all important excavations.

To Mr. Boyd

While I agree that the V-notch test is more discriminating than the various keyhole tests available it must be remembered that this is still very much a matter of national and indeed personal preference, opinion and choice, and I refer Mr. Boyd to my reply to Mr. Smedley on this subject.

The impact values given in Tables III and IV were obtained from specimens in which the notches were carefully placed at the boundary between weld metal and parent metal, the precise position being determined in each case by etching.

I wish to thank Mr. Boyd for his comment on my misuse of the term "Impact Strength", and I trust his printed protest will have the desired result.

I conclude that Mr. Boyd is referring to the ductile-brittle temperature transition range in his comment at the end of paragraph 3, and I submit that the impact values quoted in Tables III and IV do indeed give some useful indication of the shape of the curve over an interesting range.

Mr. Boyd's last question is very interesting because the problems to be met with in the repair of Pelton runners and the contemplated repair of crankshafts have much in common.

I believe that the advances in welding techniques which have taken place since the days of the general embargo on the welding of crankshaft castings are so significant that they must be recognised, and that with certain restrictions the practice can now be accepted. These restrictions should first and foremost make provision for a close appraisal of the size, position and type of defect found in the casting and should also include a very definite requirement that only experienced and qualified welders be employed on this type of work, and that they are provided with the best possible working conditions. There must be available adequate efficient means of pre-heating the whole casting and stress relieving it subsequent to the repair preferably without any intermediate cooling down, and the greatest care must be taken to ensure that only suitable electrodes are used.

The words size, position and type used in relation to casting defects above have each a particular bearing on this matter. Naturally, size is important; we are concerned with the production of castings and not fabricated crankshafts and there must be a reasonable limit to the amount of weld deposit on any such casting. Position is of vital importance because here we have to consider the nature and magnitude of the stresses in way of the defect which has been located, and this is again similar to the problem facing the engineer about to repair a highly stressed water turbine casting. The type of defect is also important. For example, a rounded type of defect such as a perfectly spherical gas pore, is not nearly so dangerous as a long narrow attenuated inclusion, and a carefully balanced judgment must be made making use of all the available non-destructive testing aids before agreeing to the welding of such castings. Having said all this, however, there remains no doubt in my mind that under properly controlled conditions, as indicated above, completely satisfactory repairs to crankshaft castings can be made.

What I have written scarcely constitutes the reply which Mr. Boyd's question merits. I have only very lightly touched upon the salient factors which have come to mind and I do feel there is scope here for a paper in itself and I hope some colleague will be encouraged to write it.

To Mr. Wormald

When considering a title for this paper I wished to make it descriptive and I thought I had succeeded. I certainly cannot believe that anyone would be frightened by it. The material had to be mentioned, the purpose for which it is employed is relevant, the locus of the activity described was included because my experience of the subject is confined to Switzerland, and as much of the paper is devoted to repair welding I felt that this fact should appear. Mr. Wormald has set aside his fears, has made a shrewd assessment of the paper's contents and has proceeded to pose some excellent questions.

Whether it is unfair or superfluous to ask what would have happened had there not been a surface crack at the position shown in Fig. 4 is readily answered by the simple negative—"neither!" The result in the case quoted would have been that a dangerous latent defect would remain in the casting. Most specifications call for the complementary use of several forms of non-destructive testing, and the deep-seated defect indicated could hardly escape a properly conducted ultrasonic test or radiographic examination, but the case could arise where the only aid to quality assessment is magnetic crack detection and I wished to bring to notice the importance of close attention to the smallest indications obtained by this means. It should never be forgotten that some very large caves have tiny entrances and I am sure Yorkshiremen, with their profusion of potholes, will be among the first to appreciate this point! I am grateful to Mr. Wormald for giving me the opportunity of returning to this subject.

Just below Fig. 4 on page 5 I inserted the reminder that final magnetic crack detection should be applied after all heat treatment has been completed, and I would amplify this with the comment that there have been numerous cases of areas, crack-detected with satisfactory results prior to the final stress relief heat treatment, which were subsequently found to contain defects, now visible at the surface and found to be arising from just such deep-seated defects as have been indicated. The advance of the crack is propagated by the effect of the thermal cycle to which the casting is subjected in heat treatment.

Mr. Wormald has correctly interpreted the purpose of the section headed "The rod for the job" and of the Tables III and IV, all of which combine to draw attention to the importance of matching the electrodes to the base material before welding begins.

The heat treatment of alloyed steels may range from the quenching and tempering of low carbon steels, to the very complex multi-stage heating and multi-stage cooling required by the highly alloyed steels, and I would advise that, in view of the specialised nature of the knowledge required, a metallurgist should be consulted for decisions as to suitable heat treatment for castings in particular alloy steels.

I will not be tempted to generalise on this complex subject which is beyond the scope of the average mechanical engineer, and will be content to draw attention to the dangers of applying heat treatment for the purpose of relieving stresses due to weld repairs which have been effected to 13 per cent chromium steel castings by the employment of electrodes of a composition which is known to become embrittled by such treatment.

It may not be out of place to mention here that the Surveyor who has accepted a casting in the rough machined, rough ground condition after exhaustive tests should not be unduly depressed when he learns subsequently that the rough machined object on which he was content to place his stamp has been found wanting when finished-machined and ground and polished. We constantly strive to improve our techniques of non-destructive testing; we apply ultrasonics, radiography, magnetic methods, etc., and we find large numbers of defects, but so far we have not been issued with the ultimate aid—the crystal ball.

ACKNOWLEDGMENTS

I wish to express my thanks to Messrs. Electro-Watt Ltd., Consulting Engineers, Zurich, for the loan of their excellent colour film of the construction of the Göschenen Power Station and dam which was shown at the reading of the paper, and to the Directors of Messrs. Sulzer Bros. Ltd., Winterthur, for the loan of the gas sampling flask, the use of which was demonstrated on the same occasion.

PRINTED BY LLOYD'S REGISTER OF SHIPPING AT GARRETT HOUSE, MANOR ROYAL, CRAWLEY, SUSSEX, ENGLAND

Lloyd's Register Staff Association

Session 1964-65

Paper No. 2

ICEBREAKERS—THEIR DESIGN AND CONSTRUCTION

by

L. J. CRIGHTON

LLOYD'S REGISTER OF SHIPPING

71, Fenchurch Street, LONDON, E.C.3

The Author of this paper retains the right of subsequent publication, subject to the sanction of the Committee of Lloyd's Register of Shipping. Any opinions expressed and statements made in this paper and in the subsequent discussion are those of the individuals.

ICEBREAKERS—THEIR DESIGN AND CONSTRUCTION

by L. J. Crighton

When this paper was first envisaged careful consideration was given to its scope and whether to limit it merely to the construction of icebreakers. However, before the construction of an icebreaker can be contemplated, some knowledge of the design of icebreakers is desirable, as, unlike the conventional cargo vessel, the design and form of an icebreaker has a very important influence on the structure to be adopted.

As both these aspects are interdependent upon each other it was decided to devote a large portion of the paper to the basic design of icebreakers.

INTRODUCTION

With the rapidly expanding population of the Earth, nations are forced more and more to explore the vast waste lands of deserts and other areas which, hitherto, had been thought uninhabitable and barren of useful mineral wealth.

Serious investigations are being carried out by nearly all the major nations of the world on the problems of survival, geological exploration and exploitation of mineral wealth to say nothing of the strategic advantages under the most extreme conditions.

It was with these thoughts in mind, coupled with the request of the Admiralty to the Society for guidance on the construction of polar icebreakers, that the Society decided, in the light of current development of icebreaker design, to investigate more fully the complex mechanics of icebreaking.

ASPECTS IN THE DESIGN OF ICEBREAKERS

The primary function of an icebreaker is to break ice. This simple fact should always be kept uppermost in the design of icebreakers and should never be allowed to become obscured with other functions or duties for which the particular icebreaker may be called upon to do.

Put simply an icebreaker is a powered tool designed to undertake its duties in the most efficient manner.

As experience over the centuries has demonstrated to man that it is easier to chop wood with an axe than with a hammer, experience has also shown the icebreaker operators the best hull form required to break ice with the minimum effort.

It is upon the wealth of knowledge and experience accumulated over the years by these icebreaker Captains and their forefathers that the present-day icebreaker owes its development.

Contrary to the usual and accepted principles in naval architecture, the design of the hull form is evolved with the principle of icebreaking efficiency in mind and not the selection of an optimum block coefficient, to give the specified deadweight or cargo capacity at the contract service speed.

It is because form is of such importance that the writer would like to see a clause on hull form written into the Rules for the construction of icebreakers.

In the design of icebreakers it is important to ascertain the geographical limits in which the vessel is expected to operate, i.e. whether in the thinner river and estuary ice or the older and thicker polar ice packs.

Broadly speaking icebreakers are of two types: (1) The Harbour and Estuary type (2) The Polar type.

Type 1 covers all types of icebreakers engaged in keeping harbours and rivers clear of ice and freeing ships trapped in ice in the more temperate zones such as the Baltic Sea and around the coast of Scandinavia, on the Great Lakes of North America, on the St. Lawrence Seaway and at the Atlantic coastline of Canada and north of the European coastline of Soviet Russia.

Type 2 covers icebreakers operating under very low temperatures such as the Arctic and Antarctic, north of Siberia and at the north coast of Canada and Greenland.

It is this type of vessel that usually supports oceanographic and geological expeditions in the Arctic and Antarctic.

As already mentioned, the form of icebreakers is of particular importance and has been developed through the years from experience gained breaking and cutting ice of various thicknesses, type and age. It is perhaps prudent therefore to look into the history and development of the icebreaker before

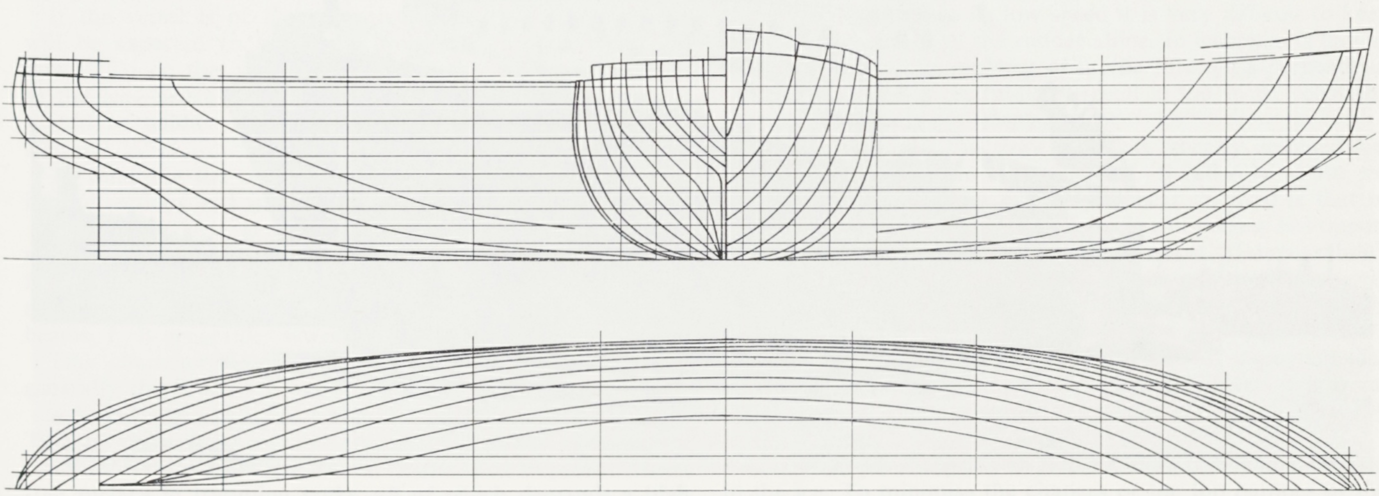


Fig. 1

Lines Plan of Triple Screw Polar Icebreaker

any criteria can be laid down as to the best design, form and strength required for icebreakers.

The first real icebreaker was the *Eisbrecker I,* which was built in Hamburg in 1871 and worked between Hamburg and Cuxhaven. Its displacement was 500 tons and its engine power was 600 i.h.p.

In 1890 the Finnish vessel *Murtaja* was built and was characterized by the full lined spoon shaped bow.

As an icebreaker she was a success in breaking clear solid ice up to about 47 cm. in thickness. However, her form made her helpless in snow-covered ice, or ice slush, as the bow pushed the snow or slush forward until she was forced to a standstill.

The experience gained from this vessel suggested that icebreakers which normally operate in thick pack ice (type 2) should have full convex bows and icebreakers which normally operate under more temperate conditions and operate in thinner, softer, snow-covered ice (type 1) should have sharper, less convex bows.

Generally speaking, to-day's polar icebreaker tries to incorporate the characteristics of both these bow forms.

At about the time the *Murtaja* was in service, development of icebreakers on the Great Lakes proceeded along new lines. Here, when an icebreaker got into difficulties it was able to force its way clear of the ice by backing into the ice.

This was achieved by fitting a bow propeller which gave the required thrust.

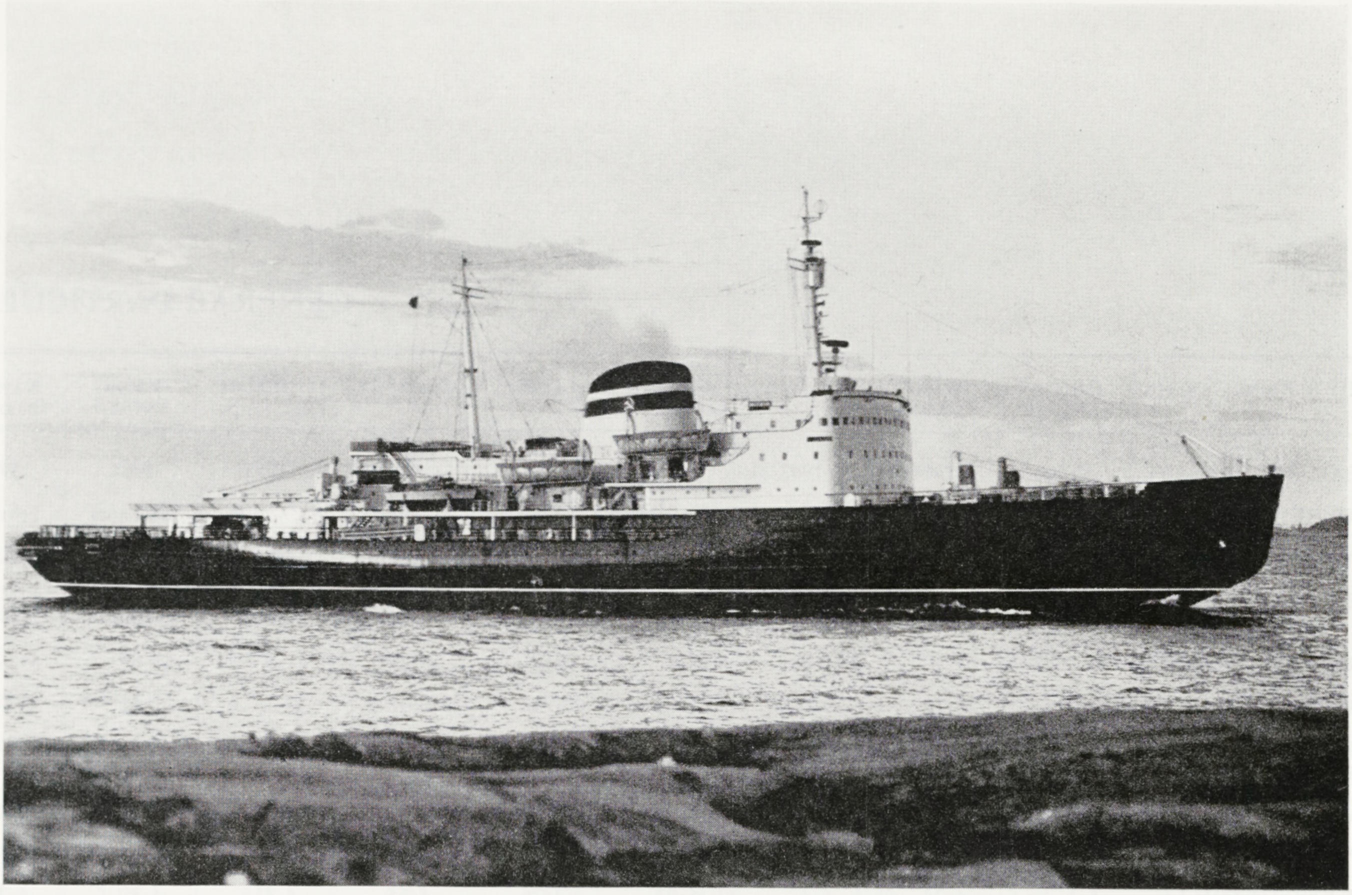
The function of the bow propeller is two-fold, one being to give the vessel good thrust when running astern and the other, which is of equal importance, is to wash away water and broken ice from the fore end of the ship when going ahead, and thus reduce friction between the ice and the bows of the ship, whilst at the same time force water into the ice pack and hence weaken the ice.

The wash of a single bow propeller is, however, non-symmetrical due to the direction of rotation, coupled to which a single forward propeller will produce a side thrust which will make steering and manœuvring more difficult—hence, sometimes, the adoption of twin bow propellers.

Icebreakers of the polar type (type 2) spend the majority of their working life operating in thick old pack ice and rely much more on their form and strength to break ice. These vessels are seldom designed with bow propellers, or, if so, are rarely fitted.

As icebreakers operate to a large extent astern it is important that the hull form in the fore body should be repeated in the after body as much as possible.

U.S.S.R. *Lenin*



U.S.S.R. *Moskva*

If the vessel is of the harbour icebreaker type (type 1) most of its life is spent in ice "cutting" as opposed to ice "breaking", and here it is important that the bow should have a fairly sharp stem with only a moderate angle between the stem and base line (generally not more than 20°).

The waterlines, however, should be slightly convex and no straight or concave sections should be permitted.

If the vessel is of the polar icebreaker type (type 2) she will be expected to break ice by virtue of her weight and power. To do this it is desirable that she should ride up on to the ice—hence the angle between the stem and base line should be neither too small nor too great (usually between 20° and 35°).

To minimise the chance of her becoming stuck fast in the ice the sections and waterlines should be convex.

Icebreakers are generally composite-purpose ships with many duties to perform but undoubtly one of the prime duties is to free a passage through the ice in which a vessel or vessels may follow. It is for this reason that icebreakers have large beams, L/B generally between 4 and 4·5.

This characteristic is also useful for other purposes, as generally the broader a vessel the easier it can break ice.

A broad beam will also result in a large metacentric height. This, however, is an essential requirement due to bad weather conditions, formation of ice on masts and superstructures, free surface in trimming tanks, all of which demands a high range of stability.

It is the duty of an icebreaker's captain to make a path through the ice where resistance is at the minimum.

This often entails a rather erratic or zig-zag course being taken. It can be appreciated therefore that manœuvrability is of prime importance which again indicates a low L/B ratio.

However, when an icebreaker moves through the ice, the fore part of the vessel is laterally deflected upon impact with the ice, and, owing to its low speed it is very difficult to keep on course by means of the rudder alone. In icebreakers having an L/B too low, the moment of inertia through a perpendicular axis through its centroid will result in the vessel becoming very sensitive to lateral displacement.

It is to overcome this drawback that recently designed icebreakers are tending to increase the L/B ratios to about six. However, the overriding principle to bear in mind is that of manœuvrability and a longer icebreaker will possess less opportunity to manœuvre than a shorter icebreaker. Manœuvrability should also be borne in mind when the bow lines are designed, as a sharper bow has better manœuvrability than a spoon bow.

To enable an icebreaker to ride the ice it is important that vertical or concave planes should be avoided and it is usual for the side plating amidships to be inclined not less than 15° to the vertical.

It is often necessary for an icebreaker to free vessels trapped in the ice. To minimise the chances of the top hamper of the icebreaker colliding with the trapped vessel upon breakage

TABLE I

GENERAL PARTICULARS

SHIP'S NAME	ERNEST LAPOINTE	"WIND" CLASS	ABEGWEIT	EDWARD CORNWALLIS	THULE	d'IBERVILLE	LABRADOR	VOIMA	KAPITAN BELOUSOV
YEAR BUILT	1941	1944	1947	1949	1951	1953	1953	1954	1955
WHERE BUILT	CANADA	U.S.A.	CANADA	CANADA	SWEDEN	CANADA	CANADA	FINLAND	FINLAND
NATION	CANADA	U.S.A.	CANADA	CANADA	SWEDEN	CANADA	CANADA	FINLAND	U.S.S.R.
LENGTH O.A.	184′ 6″	269′ 0″	372′ 6″	259′ 0″	204′ 0″	310′ 6″	269′ 0″	274′ 0″	273′ 0″
,, B.P.	172′ 0″	250′ 0″	348′ 0″	240′ 0″	—	285′ 0″	250′ 0″	265′ 0″	265′ 0″
BREADTH, EXTR.	36·17′	63·5′	61·08′	43·7′	52·8′	66·83′	63·8′	63·67′	63·67′
DRAUGHT	15·0′	25·75′	19·0′	18·04′	15·92′	30·42′	30·1′	22·12′	23·0′
DISPLACEMENT (Tons)	1510	5300	6900	3700	1930	9930	6490	4415	5360
C_B	0·632	0·465	0·607	0·67	0·456	0·59	0·50	0·482	0·489
SPEED IN KNOTS	13·0 (T)	16·0 (T)	16·0 (T)	13·5	15·0	14·5 (T)	16·0 (T)	—	16·5
LENGTH O.A. / BREADTH, EXTR.	5·1	4·24	6·1	5·93	3·76	4·65	4·21	4·3	4·29
MACHINERY	Steam Recip.	Diesel Electric	Diesel Electric	Steam Unaflow	Diesel Electric	Steam Unaflow	Diesel Electric	Diesel Electric	Diesel Electric
TOTAL H.P.	2000 I.H.P.	10000 S.H.P.	13200 S.H.P.	3500 I.H.P.	5550 S.H.P.	10800 I.H.P.	10000 S.H.P.	10500 S.H.P.	10500 S.H.P.
SHAFTS AFT	2 at 1000 I.H.P.	2 at 5000 S.H.P.	2 at 3850 S.H.P.	2 at 1750 I.H.P.	2 at 1850 S.H.P.	2 at 5400 I.H.P.	2 at 5000 S.H.P.	2 at 3500 S.H.P.	2 at 2700 S.H.P.
SHAFTS FWD	—	3333 S.H.P.	2 at 3850 S.H.P.	—	1 at 1850 S.H.P.	—	—	2 at 1750 S.H.P.	2 at 2700 S.H.P.
R.P.M. OF PROPS.	140	145	155	140	145	145	145	120	120
TOTAL H.P/DISPL.	1·32	1·89	1·91	0·95	2·88	1·09	1·54	2·38	1·96
TOTAL H.P/B. EXT.	55·4	157·5	216·0	80	105	162	157	165	165
RISE OF FOREFOOT	20°	30°	22°	25°	23°	30°	30°	25°	25°

(T) indicates Trial speed.

TABLE I

OF ICEBREAKERS

Glacier	William Carson	Oden	Montcalm	Karhu Class	Moskva	John A. Macdonald	Perkun	SHIP'S NAME
1955	1955	1957	1957	1958	1960	1960	1962	YEAR BUILT
U.S.A.	Canada	Finland	Canada	Finland	Finland	Canada	England	WHERE BUILT
U.S.A.	Canada	Sweden	Canada	Finland	U.S.S.R.	Canada	Poland	NATION
309′ 3″ 290′ 0″	351′ 0″ 325′ 0″	273·5′ 254·2′	220′ 0″ 202′ 0″	243′ 0″ 224′ 0″	400′ 6″ 368·8′	315′ 0″ 290′ 0″	180′ 0″ 160′ 0″	LENGTH O.A. ,, B.P.
74·0′	69·67′	63·6′	48·3′	57·0′	80·6′	70·25′	45·83′	BREADTH, EXTR.
25·75′	19·4′	23·0′	16·34′	19·0′	35·0′	28·1′	16·33′	DRAUGHT
8300	7720	5260	2950	3370	15400	8900	1760	DISPLACEMENT (Tons)
0·537	0·615	0·495	0·69	0·487	0·475	0·527	0·492	C_B
—	15·0 (T)	—	13·0	—	18·0	15·5	14·0	SPEED IN KNOTS
4·18	5·04	4·3	4·55	4·26	4·98	4·49	3·93	LENGTH O.A. / BREADTH, EXTR.
Diesel Electric	Diesel Electric	Diesel Electric	Steam Unaflow	Diesel Electric	Diesel Electric	Diesel Electric	Diesel Electric	MACHINERY
21000 S.H.P.	10000 S.H.P.	10400 S.H.P.	4000 S.H.P.	7500 S.H.P.	22000 S.H.P.	16500 S.H.P.	3300 S.H.P.	TOTAL H.P.
2 at 10500 S.H.P.	2 at 5000 S.H.P.	2 at 3475 S.H.P.	2 at 2000 S.H.P.	2 at 2500 S.H.P.	1 at 11000 S.H.P. 2 at 5500 S.H.P.	3 at 5500 S.H.P.	2 at 1650 S.H.P.	SHAFTS AFT
—	1 at 3330 S.H.P.	2 at 1725 S.H.P.	—	2 at 1250 S.H.P.	—	—	—	SHAFTS FWD
—	136	120	145	135	115	130	142	R.P.M. OF PROPS.
2·54	1·3	1·98	1·36	2·23	1·43	1·86	1·88	TOTAL H.P/DISPL.
284	144	163	83	132	273	235	72	TOTAL H.P/B. EXT.
30°	25°	22°	26°	25°	25°	30°	33°	RISE OF FOREFOOT

of the ice, it is thought desirable that some tumblehome be given to the icebreaker.

Should the icebreaker become firmly fastened into the ice and backing becomes impossible, heeling and trimming tanks are built into the structure with very large capacity pumps and associated piping. Sea water is rapidly transferred from one side of the vessel to the other, or from an after trimming tank to a forward tank, or a combination of both actions, until the vessel fractures the surrounding ice sufficiently for her to use the propellers to complete the job. To enable the heeling action to have the best effect it is usual to have a large bilge radius. In later icebreakers the oil fuel is used in the heeling tanks instead of sea water. It is obvious from the foregoing that underwater appendages should be avoided as much as possible.

Because of this heeling action it is thought desirable that the freeboard should take into account a design draught corresponding to an angle of list of say 20° before the decks become awash.

With regard to draught, it should be sufficient to accommodate large propellers, provided of course that draught is not restricted in any way. It is important that the propellers should be placed as low as possible in order that the blade tips do not touch firm ice and also the propeller does not draw down air.

The blade tips should not work below the base line nor outside the vertical projection of the load waterline.

Icebreakers have very fine forms with block coefficients in the region of 0·47 to 0·51 although Canadian icebreakers have block coefficients slightly higher. The position of the L.C.B. does not have the same hydrodynamic importance for icebreakers as for conventional vessels and can be placed to suit the weight distribution to give the best icebreaking effect. This generally means placing the L.C.G. as far forward as possible, consistent with good icebreaking lines.

To give the maximum height forward to keep the fore decks clear it is desirable to fit a forecastle.

The success of an icebreaker is its ability to break ice. The two most important factors for breaking ice are weight and the power to use this weight.

It is for this reason that icebreakers are designed on horsepower/ton of displacement.

Having decided upon the size of icebreaker required for a particular service, bearing in mind location, range of operation and terrain likely to be met, the displacement is very quickly deduced.

It is upon this result that the horsepower of the main machinery is determined.

Generally, for polar icebreakers the h.p. per ton of displacement lies in the region of 1·80 to 2·90 (see Table I).

It is not necessarily prudent to increase the b.h.p. to give an excessive b.h.p./ton as the icebreaker may then break off very large pieces of ice, which, after passing under the vessel, will only block the path already cleared.

It can be seen, therefore, that any formula derived involving the strength of icebreakers should preferably have some connection with horsepower and displacement.

Another important characteristic in icebreaking is the beam, and, as it is not always possible to have the displacement of the proposed icebreaker to hand at the design stage, it is considered more practical to use the beam of the vessel instead of the displacement in any strength formula used.

Because the function of an icebreaker is to exist on a collision course it is very susceptible to heavy damage. It is important therefore that a double bottom be arranged extending all forward and aft, carried up at the sides to the nearest deck, flat or stringer.

The subdivision forward and aft should therefore be investigated.

It is the practice for Canadian icebreakers to design for at least one-compartment standard of flooding.

Broadly speaking, the basic fundamentals to keep in mind for the design of an icebreaker can be summarised as follows:—

1. Generally, the form to be convex throughout with no flat or concave sections or waterlines.
2. The icebreaking characteristics of the forward body to be incorporated as far as practicable in the after body.
3. Angle between stem and base line to be not less than 20° and not more than 35° for polar icebreakers.
4. Bottom forward to be well curved.
5. Side plating amidships to be inclined to the vertical.
6. Where a vessel's function is to free vessels lying alongside, tumblehome should be arranged.
7. Freeboard should take into account a list of say 20° before decks become awash.
8. Large bilge radius to be arranged.
9. Forecastle should be fitted.
10. Underwater appendages to be avoided as much as possible.
11. Heeling tanks and trimming tanks to be provided with a large capacity pumping plant in order that water may be transferred from one side of the vessel to the other quickly.
12. Subdivision forward and aft should be investigated.
13. A double bottom extending all forward and aft, the vertical extent of which to be determined in association with stringers, decks, flats and subdivision.

PROPULSION

Due to the remoteness of duty, and the possibility of the icebreaker being unable to free itself from ice floes for long periods of time, the machinery plant must be economical in fuel consumption and the vessel must carry a supply of fuel to provide for long periods of full power and immobilisation. The necessity to refuel may result in missing favourable weather conditions, therefore a maximum radius of action is one of the most important requirements in modern icebreakers.

Icebreakers have a high power/length ratio and due to the specialised nature of the vessels, space is at a premium.

For these and other reasons modern icebreakers usually have diesel-electric propulsion machinery. However, in the case of icebreakers having enormous power the diesel-electric system is more complex in installation and operation owing to the large number of diesel generators required.

It would appear, therefore, that the Russians had these problems in mind, no doubt in conjunction with others, when their latest icebreaker *Lenin* was fitted with atomic propulsion.

The advantages of atomic propulsion would seem to fit the needs of a polar icebreaker admirably, giving in addition to the absence of fuel problems, almost unlimited radius of action and navigation scope, for long periods of time.

The propelling and shafting system is subjected to high shock loads from both solid and broken ice, requiring machinery that will not be heavily stressed by sudden and heavy

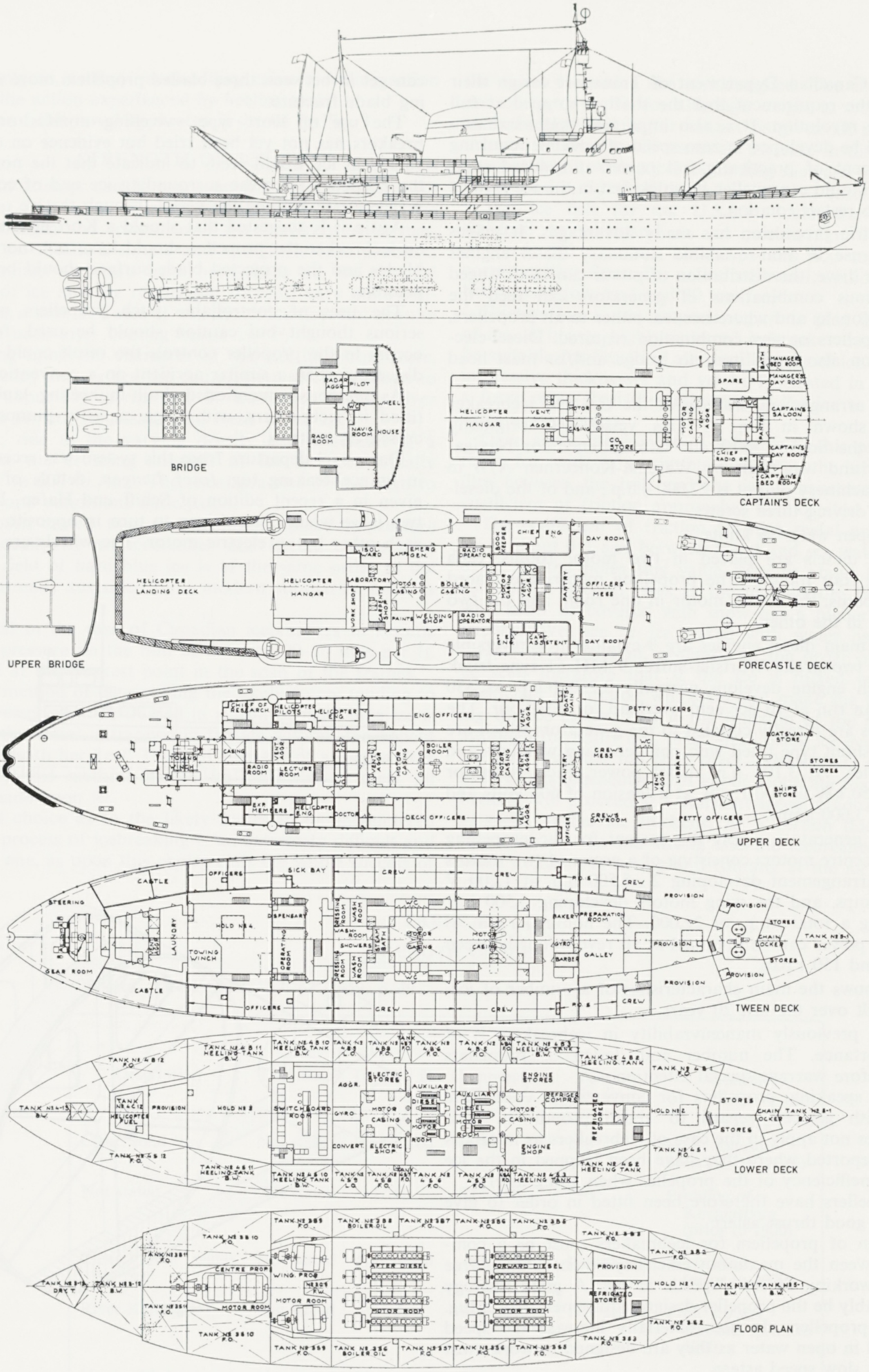


Fig. 2
General arrangement of U.S.S.R. *Moskva*

shocks. The Canadian Department of Transport design their shafting on the requirement that the shaft is stopped at full speed in one revolution. It is also important that maximum thrust should be developed at zero speed of advance requiring the development of practically full power at reduced shaft revolutions. Should a propeller be stuck fast in the ice it must be possible to restart rotation.

Diesel-electric propulsion has many advantages. It makes possible the use of non-reversible stationary diesel engines for generator drive, the distribution of power can be arranged so that various combinations of generators can feed the propeller motors as and where needed, either to all propellers, forward propellers or any combination required. Diesel-electric propulsion also lends itself to bridge and/or mast head control.

A general arrangement drawing of the U.S.S.R. icebreaker *Moskva* is shown in Fig. 2. This vessel was originally classed with the Society ✠100A1 "Strengthened for Navigation in Ice" and was built by Wärtsilä-Koncernen A/B in 1959. The machinery output is 22,000 s.h.p., and of the diesel-electric type driving three screws.

Speed in open water 18 knots.

The main diesels are placed in two motor rooms, each room having four motors. The propelling motors are placed aft in two rooms, the centre motor in one room and the two wing motors in the other.

The eight main diesel engines are 9-cylinder non-reversible single-acting two-stroke Wärtsilä-Sulzer 9 MH 51 type trunk engines. Each engine develops normally 3,250 b.h.p. at 330 r.p.m. but can run at 10 per cent overload for one hour. The diesel engines are directly coupled to the generators which are of the D.C. shunt type fitted with compensating windings and auxiliary poles. At 3,100 h.p. diesel power, each generator develops 2,150 kW at 330 r.p.m. at a tension of 600 volts and a current of 3,600 amps.

The main generators supply the current for the propelling motors, the centre motors consisting of a group of two motors in tandem arrangement developing $2 \times 5{,}500$ h.p. at 1,200 V and 3,600 amps, and the wing motors developing 5,500 h.p. each, making a total s.h.p. of 22,000. The nominal r.p.m. is 115 but full power can be obtained at all revolutions between 110 r.p.m. and 150 r.p.m.

Table I shows the main characteristics of a number of icebreakers built over the last 20 years.

As stated previously manœuvrability in icebreakers is of prime importance. The number and design of propellers should therefore warrant special attention.

Generally speaking, propellers for conventional vessels are designed with greatest regard to ahead propulsion. This criterion does not apply in the case of icebreakers as instances have been reported where they have been trapped in the ice due to the inefficiency of the propeller when going astern.

Bow propellers have therefore been fitted in order to give the vessel a good thrust astern.

The design of propellers for icebreakers must be a compromise between the maximum efficiency when running free and when working at slow speeds in ice. A good analogy would probably be the propeller design requirements for a tug.

Forward propellers do not materially increase the speed of the vessel in open water as they are designed to work most efficiently at slow speed astern.

It is generally thought that four-bladed propellers are a better proposition than three-bladed, as larger pieces of ice can get in between three-bladed propellers more readily causing blade fracture.

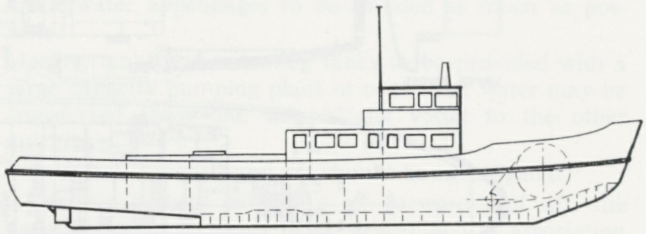
The use of Kort type swivelling nozzles on polar icebreakers has not yet been tried but evidence on conventional vessels in ice would seem to indicate that the nozzle protects the propeller from the surrounding ice and of course gives a bigger thrust helping the vessel through the ice.

Again it is suggested that should a Kort nozzle be fitted to an icebreaker the propeller should have not more than three blades and the projected blade surface should be as small as possible.

The uses of controllable pitch propellers may warrant serious thought but caution should be used, for if failure occurs to the propeller controls the result could be far more disastrous than a similar accident on a conventional vessel.

As previously mentioned, built-in heeling tanks are often fitted in icebreakers, with large capacity pumps and piping cross-over systems.

One novel departure from this system was recently installed in an icebreaking tug, *Josef Langen*, details of which were given in a recent edition of Schiff und Hafen. It consists of two large wheels belt driven to turn in opposite directions to each other by an electric motor. The wheels are weighted on



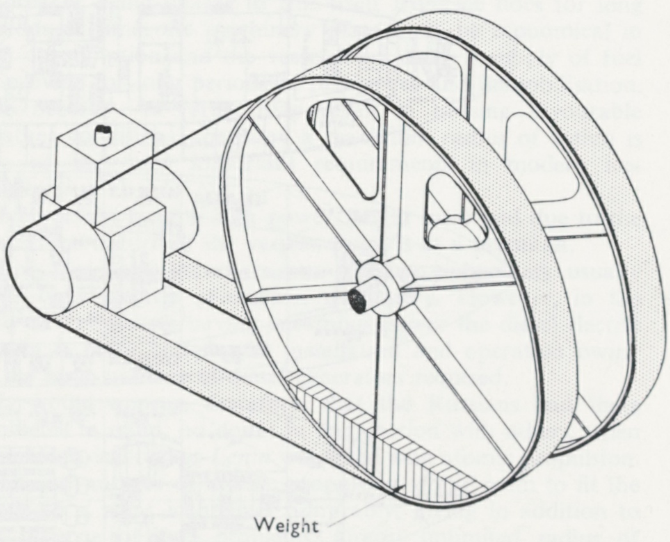


FIG. 3

Josef Langen (sketch of rolling apparatus)

one side only so, as they revolve they cause a rolling action similar to the action experienced by heeling tanks.

A sketch of this novel apparatus is shown in Fig. 3.

STRENGTH OF ICE

Before an attempt can be made on the likely hull strength required for icebreakers it is necessary first to determine the probable strength and resistance of the ice likely to be met. This is by no means a simple and straightforward problem. Many soundings and tests have been made on the physical properties of ice and the results put forward vary quite considerably, as a look at Table II will show. Ice does not acquire its strength until after cooling below 16° F.

Depending upon the character of the ice, its temperature, its constituency and its age the compressive strength seems to vary from about 300 lb./in.^{2} for St. Lawrence Seaway river ice to 3,000 lb./in.^{2} for clear, solid fresh water ice.

However, due to the varying density and condition of a mass of ice the crushing strength of ice is more usually 400 lb./in.^{2} to 600 lb./in.^{2}. The usual practice is to design to meet the worst conditions anticipated.

It has been stated that the maximum possible pressure sustained locally by an icebreaker due to the compressive force of a field of hard blue ice is of the same order as the pressure normally sustained by a modern submarine over its entire hull.

It is usual in the case of Canadian icebreakers to assume a band of pressure on the hull of between 20–30 tons per ft. run, placed at the weakest point in the span of the frames.

Another method of determining the likely forces tending to crush the vessel when restrained in a field of hard blue ice is to assume the vessel is trapped in the ice without the benefit of water beneath her keel. The hull strength of an icebreaker designed by this method should be sufficient to meet all demands made upon it.

The final choice as to the likely forces to be encountered during the process of icebreaking is an extremely difficult and unenviable one, as upon this choice rests the whole success of the vessel for which she was designed. The choice is usually one of compromise, for although weight is very important to an icebreaker this factor cannot be given all priority, for an increase in weight will mean an increase in dimensions for a given draught, with a corresponding increase in power, all of which pushes up the already high capital costs.

The ice belt for the U.S.S.R. icebreaker *Moskva* was designed to withstand an ice pressure of 1,000 tons/m.^{2} forward, 600 tons/m.^{2} amidships and 800 tons/m.^{2} aft. A corresponding figure for a normal vessel would be something between 15 tons/m.^{2} and 30 tons/m.^{2}.

Friction has a very important part to play in the breaking of ice. A heavy, highly-powered icebreaker may theoretically be suitable for breaking almost all kinds of ice of up to quite impressive thicknesses and yet be frustrated in her efforts by a force other than the resistance of the ice to fracture. This force is friction.

Once again the important solution to this problem is hull form, for, with an unsuitable hull form, the lubricating water film between the hull and the ice is squeezed out and the coefficient of friction approaches that of steel on steel.

The coefficient of friction between metal and fresh water ice is about 0·1 and between metal and sea water ice is about 0·15. At the poles this value rises to about 0·20. The coefficient of friction rises as the temperature falls, ice mixed with snow or covered with snow has a higher coefficient of friction. Wet ice or ice mixed with water has a very low coefficient of friction, generally in the order of 0·01. It can be seen therefore that if the ice is mixed with water the coefficient of friction will drop and make the task of breaking the ice easier. This is the function of the bow propeller, although for really old, thick, hard, pack ice even the wash of the bow propeller has little effect. Where there is a predominance of homogeneous, firm ice of moderate thickness the icebreaker will proceed at a constant speed, gradually decreasing in speed as the ice thickens. At a certain thickness the ice resistance will be too strong and the icebreaker will have to make attacks—reversing and running at the ice at full speed.

TABLE II

STRENGTH OF ICE

Source—S.N.A.M.E., Vol. 67, 1959, p. 49

Description	Thickness	Temp. ° F.	Strength: Compression lbs./in.^{2}	Strength: Tension lbs./in.^{2}	Source
Clear, solid ice	Not stated	Not stated	3000	250	H. F. Johnson SNAME 54 (1946)
Not stated	Not stated	—1° C.	213–388	190	Fruhling of Koenigsberg (prior to 1900)
Clear, fresh water ice pan	Not stated	Not stated	327–1000	Not stated	W. Ludlow (prior to 1900)
River Kennebec	Not stated	—4° F.	399– 970	Not stated	Prof. Kolster Helsinki (prior to 1900)
Hard, old Arctic ice	Not stated	Not stated	1000	250	A. Watson IME 1958

Ice is relatively weak in tension but very strong in compression.

Observations have shown that ice is first partly cleaved by radial cracks and, secondly, broken by bending at right-angles to the radial cracks. The broken pieces of ice are then forced under the hull and thrown clear by the wash of the stern propellers. The efficiency by which the icebreaker is able to push the broken pieces of ice beneath its hull is a direct function of its form, as are the sizes of the pieces of ice broken, for it is vital that these pieces are not so large as to prevent the propellers throwing them clear. It is also vital that the pieces broken should not be so large as to block the path just cleared.

ICEBREAKING FORCES

A considerable amount of work has been done on this subject, mainly by the Russians, Canadians and North European countries, and it is to these that one has looked in the past for the major research work on the development and mechanics of icebreaking.

Reference is given at the end of the paper to some of the work done on the theoretical approach to the mechanics of icebreaking.

It is not proposed in this paper to delve too deeply into this complex problem but rather to put forward the broad assumptions made and the general conclusions to be drawn.

Broadly speaking there are three aspects of icebreaking, namely:—

1. Breaking firm homogeneous ice of such a thickness the icebreaker may proceed at a constant speed.
2. In heavy ice of such a thickness that it is necessary for the icebreaker to make attacks by reversing and then running full speed at the ice.
3. Working in moving, twisting, pack ice and in ice of a non-homogeneous nature involving pure ice and a mixture of ice and snow.

Considering each case in turn:—

CASE 1. There are several forces involved in the breaking of ice but broadly speaking the real work is done by three forces, namely, Inertia forces, Vertical crushing force and Friction forces, the last force being very difficult to determine as it has a direct bearing on the constituency of the ice and on the type and condition of the hull and whether it is welded or riveted.

The Inertia force is the force transmitted to the ice by virtue of the kinetic energy of the ice being pushed forward by the icebreaker coupled with the breadth of the vessel and the thickness of the ice in contact.

Dr. Techn. Jan-Eric Jansson in his paper on "Icebreakers and their Design" read at the Scandinavian Ship-Technical Conference in Oslo in October, 1956, put forward an expression for these Inertia forces of the following order:—

$$R_{in} = K \frac{Y}{2g} V^2 Be$$

where R_{in} = inertia forces in Kg.

Y = sp. weight of ice, approx. 900 kg/m.^{3}

g = acceleration due to gravity (9·81 m/sec.^{2})

V = speed of vessel in m/sec.

B = breadth of vessel at waterline in metres

e = thickness of ice in metres.

The constant K depending upon the form of the ship's hull, i.e. the angle between the hull plating and the plane of the ice, etc.

Dr. Techn. Jan-Eric Jansson also gives an expression for the vertical crushing force which bends the ice to fracture. This force can be calculated theoretically by considering the vertical force per unit length on the edge of a floating ice beam of constant thickness and infinite length. He gives this required force as proportional to $e^{5/4}$ where e is the thickness of the ice.

The total ice force is a combination of the above forces dependent upon the thickness of the ice and the speed of the vessel. For normal hull forms of icebreakers the ice resistance can approximately be written:—

$$R = (C_1\ e + C_2 eV^2)\ B$$

where C_1 and C_2 are experimental constants derived as a function of hull form, etc.

CASE 2. Icebreaking in bursts: For very thick ice it is not possible for the icebreaker to break ice at a constant speed but to make runs at the ice. In this case the speed and hence the kinetic energy is reduced to zero and the kinetic energy is abruptly converted into icebreaking work. Generally, however, the icebreaking forces are of the same type as for breaking thinner solid ice as in Case 1. It is in this type of work, however, that the mass inertia and power of the vessel play such an important role.

CASE 3. Icebreaking in pack ice: Many icebreaker captains consider this form of ice breaking to be the most hazardous. Pack ice is constantly moving and twisting and altering its constituency—sometimes it is heavy thick solid ice, sometimes a snow covered ice mixture which, owing to its unpredictable condition, produces the greatest difficulties. It is not possible, as with ice at rest, to skirt the ice pack, as the ice is continuously moving.

It is in pack ice that the bow propellers are of most use.

MODEL EXPERIMENTS IN ICE BREAKING

Attempts have been made to determine the forces involved when breaking ice by model experiments. These experiments are difficult to perform owing to the problem of reproducing the ice conditions on a model scale, and, to date, do not seem to produce really worthwhile results when compared with actual ship data available.

Dr. Techn. Jan-Eric Jansson has, however, put forward a method whereby ice breaking in bursts can be determined from model experiments. In this method he proposes an expression whereby the vertical crushing force can be determined.

A roller, capable of rotating about its own axis, is placed on the water at right angles to the path of the model. The variation in the vertical forces can then be investigated either by measurement on the roller or through observations of trim, etc., on film.

Fig. 4 shows an icebreaker in contact at the stem with the edge of the ice.

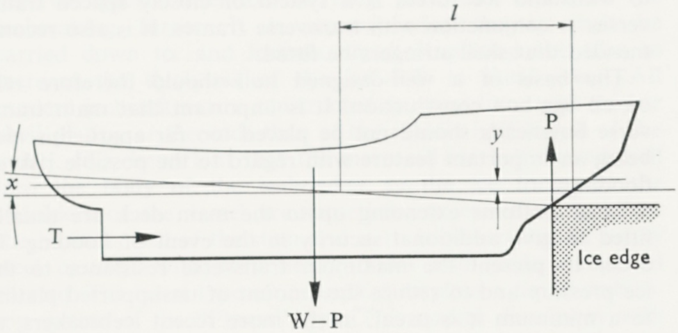


FIG. 4

The following nomenclature is used:—

W = weight of vessel.

P = vertical force between vessel and edge of ice.

T = propeller thrust (total from all propellers; a function of speed).

M = mass of vessel + virtual mass of water.

J = moment of inertia of mass of vessel + virtual added mass of water, referred to a horizontal axis through centre of gravity and at right angles to the lateral plane.

V = speed of vessel in knots.

s = length co-ordinate.

y = vertical co-ordinate.

x = angle of trim.

ω = angular velocity about a horizontal axis at right angles to the lateral plane.

p = number of tons load for l metres immersion.

q = trim moment in ton metres for 1 radian of trim.

l = distance from centre of gravity of waterline areas to foremost point in the waterline (centre of flotation).

(The change in trim is assumed so small that the last three quantities are taken as constant.)

As the friction force is very difficult to determine it is usual to neglect it for model experiment work and make an adjustment to the resulting forces obtained at the end.

Once again the principle of the conservation of energy is applied in that the kinetic energy of the vessel, plus the propeller's thrust acting through the distance travelled, is dissipated into three channels, namely:—

1. Energy dissipated by impact of the bow of the ship on the ice belt.
2. Potential energy of the ship due to its being raised and changed in trim and deflected, and
3. Frictional loss caused by the rubbing of the vessel against the ice shelf.

Items 1 and 2 can be written so:—

$$\tfrac{1}{2}\,M(V_1^2-V_2^2)+\int_{S_1}^{S_2}T\,ds=\int_{Y_1}^{Y_2}py\,dy+\int_{x_1}^{x_2}qx\,dx+\tfrac{1}{2}\,J\,(\omega_2^2-\omega_1^2)$$

The maximum vertical force can be said to act when the vessel has come to a halt. In this condition the angle of trim has reached its maximum value and the angular velocity is zero.

If we substitute $V=o$, $\omega=o$, $\omega_1=o$, $y_1=o$, $x_1=o$, we obtain from the above expression the maximum icebreaking work the vessel can do

$$\tfrac{1}{2}\,MV_1^2+\int_{S_1}^{S_2}T\,ds=\frac{py_2^2}{2}+\frac{qx_2^2}{2}$$

If we take $P=py$ and $Pl=qx$; by eliminating P we get

$$y=\frac{qx}{pl}$$

Substituting this value for y in the above expression we get

$$\tfrac{1}{2}\,MV_1^2+\int_{S_1}^{S_2}T\,ds=x_2^2\left(\frac{q^2}{2pl^2}+\frac{q}{2}\right)$$

The expression in parentheses is constant.

The icebreaking force is therefore directly proportional to the square of the change in trim.

As stated earlier $Pl=qx$, $\therefore\ x=\frac{Pl}{q}$ or it can be stated that the icebreaking force is also proportional to the square of the vertical force P. Thus by estimating the maximum angle of trim likely to be obtained by the design of the icebreaker it is also possible to calculate approximately the maximum icebreaking work it is likely to achieve.

In the above equations friction forces have been neglected. If it is desired to make some allowance for this force it is possible to do this by resolving the icebreaking force given above into a force taken normal to the shell either graphically or by calculation, with an appropriate allowance being made for the coefficient of friction.

PRINCIPAL HULL SCANTLINGS

Up to the time of writing this paper the rules for the determination of principal hull scantlings for polar and non-polar icebreakers were not finalised. The following notes must therefore be considered only as suggestions.

As mentioned earlier the design and construction of icebreakers is an art almost entirely evolved from experience and the determination of scantlings should be, and in fact is, influenced to a very large extent by practical considerations.

It has to some extent been the limitations of the shipyard's ability to work the very thick materials into the rounded hull form that has determined the maximum limit of hull scantlings, in particular, shell plating.

To date, it has been the practical considerations which to a large extent have determined the scantlings of webs, frames and stringers, no little importance being given to the question of access. Considerable thought has been given by authorities on these aspects and it is for this reason that the spacing of shell frames is generally of the order of 16 in., almost irrespective of length of ship, this being the minimum frame spacing thought practical for access.

It can be seen, therefore, that although it may be possible to draw up a set of Rules based on theoretical parameters, very serious consideration has to be given to the practical limitations regarding working of the materials. Some countries, noticeably Russia, seem to have recognised these limitations for conventional icebreakers and are at the present time investigating quite revolutionary methods of icebreaking.

Two instances noticed in recent publications of "Fairplay Shipping Journal" underline the latest ideas being considered

by the Russians, one being a design by Leningrad engineers of a powerful icebreaker which uses large circular saws to cut its way through the ice. A scale model of this icebreaker has already been successfully tested in a special basin. The icebreaker will be used for cutting channels in stationary icefields in harbours and ports. The flat rectangular nose of the vessel when coming in touch with the lower rim of the icefield will push its way through the cut pieces of ice and throw them aside with the aid of a simple device, thus leaving an ice-free channel in the wake of the ship. The other design is an icebreaker claiming to be five times more efficient than conventional icebreakers. The principle is to use jets of water ejected at supersonic speed from the ship and underwater wings to clear the crushed ice from the opened channels.

Before principal scantlings can be determined it is very important to ascertain the probable geographic limitations likely to be imposed on the vessel, for it is upon these limitations that the class of icebreaker is likely to be given.

Broadly speaking, there are two main classes of icebreaker: (1) non-polar icebreaker, (2) polar icebreaker.

As non-polar icebreakers do not operate under the same extreme conditions as polar icebreakers, the scantlings for the principal hull items could be somewhat less than for polar icebreakers.

In order to resist the very great pressures exerted by the ice on the hull of the vessel it is of vital importance that the transvere strength of icebreakers be sufficient to meet these forces. It is for this reason that icebreakers are framed on the transverse system. Longitudinal strength is not of such importance, although, because of the large scantlings of the principal hull members there is a good surplus, for instance, the section modulus of the "Wind" class icebreakers is in the order of three times the Load Line section modulus required for a conventional vessel of the same dimensions.

To draw up a basis for determining the principal hull scantlings of icebreakers it should be appreciated that a different approach to the methods normally adopted for conventional vessels is required.

In conventional vessels the main hull parameters such as length, breadth, depth, draught and frame spacing are the governing factors which determine the bulk of the principal scantlings. For icebreakers, however, this is broadly speaking not the case. Local strength requirements assume a more important role. Using the theoretical icebreaking force imposed upon the hull by the method described earlier, it is possible to relate this force to the relative icebreaking strength of present icebreakers in the form of power/displacement ratios, or as products of the displacement and horsepower, and apply these ratios to the principal hull items.

In the U.S.C.G. "Northwind" class icebreaker, the midship section was designed with a double skin extending up to the main deck supported by truss frames. The scantlings of these truss frames were determined by the Hardy Cross moment distribution method with the framing considered as rigid joint trusses.

As mentioned earlier, longitudinal strength of icebreakers is in abundance, however, the strength deck should be sufficient to withstand the quite large sagging forces imposed due to the vessel riding out of the water on to the ice. Large house structures on this deck should also be strengthened because of these forces. The deck nearest the waterline should be strong enough to withstand the ice pressure.

In general, decks are spaced closer together than transverse bulkheads. Consequently, the most efficient system necessary to withstand ice forces is a system of closely spaced transverses in conjunction with transverse frames. It is also recommended that shell stringers be fitted.

The basis of a well-designed hull should therefore rely on an egg-box construction. It is important that main transverse bulkheads should not be placed too far apart, this also being an important feature with regard to the possible risk of flooding.

Inner bottoms extending up to the main deck are usually fitted to give additional security in the event of flooding. In order to present the maximum transverse resistance to the ice pressure and to reduce the amount of unsupported plating to a minimum it is usual, in the more recent icebreakers, to fit cant frames at the ends of the vessel as near normal to the shell plating as possible, as shown in Fig. 5.

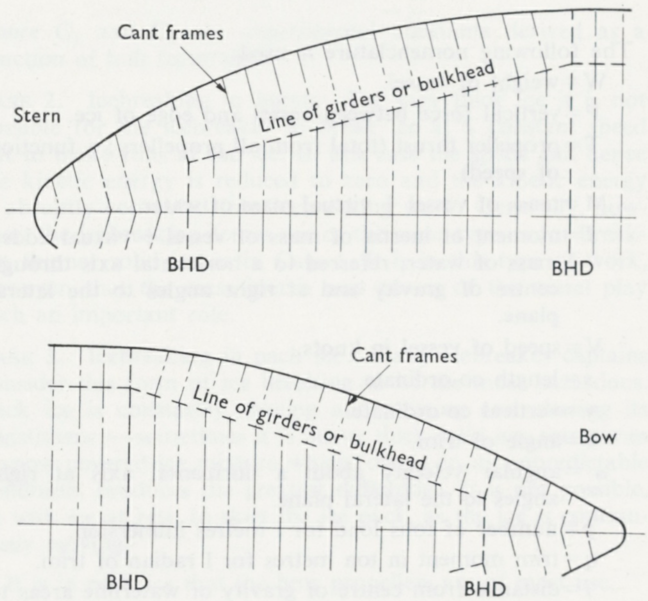


FIG. 5

It is important the double bottom should extend for the full length of the vessel with solid floors throughout.

To resist the sudden accelerating and decelerating forces associated with icebreaking it is important that engine seatings and other foundations be made extra strong. Similarly, minor bulkheads and other light structures, in general, should be stiffened to resist these forces.

The requirements of shell plating in way of the ice belt is the subject of much controversy. Some authorities are of the opinion that the thickness of shell should only be limited by practical considerations and subscribe to the theory that you just cannot have the ice belt too thick, whereas other authorities are of the opinion that an ice belt thickness in excess of 2 in. serves little useful purpose, as beyond this point increase in icebreaking efficiency can only be obtained by either modifying the form of the icebreaker or by revolutionary methods, some of which are mentioned earlier.

However, all authorities seem to agree upon the extent of the ice belt, that is, between 2 to 5 ft. above the operating waterline down to 10 to 20 ft. below the operating waterline. The reason for the major portion of the ice belt being below the waterline is because the broken pieces of ice are forced downwards below the waterline. The ends of icebreakers

deserve special attention as they take the brunt of the icebreaking forces. It is recommended the ice belt be carried down to, and include, the keel plating and also to increase the thickness of the ice belt in these areas. All modern icebreakers are constructed on these lines with thicker shell plating at the ends than at the middle half length of the vessel. It is important that the increased ice belt extend well into the body of the icebreaker as the ice forces at the shoulders of the vessel are sometimes excessive. Quite often the business end of the stem and stern is constructed of heavy steel castings with very heavy floors and girders attached thereto. The latest type of icebreaker employs a liquid stabilising system of the "Flume" type. This system does away with external appendages and has the added advantage that the stabilising tanks can be controlled to rock the vessel for additional icebreaking work.

Thickness of internal members such as web frames, wing plating of transverse bulkheads, stringers, etc., should bear some relationship to the thickness of the adjoining shell and it is suggested that a minimum thickness of these members, say as a percentage of the shell thickness, be adopted.

Scantlings of the sternframe, pintles and gudgeons, etc., and the rudder and rudder stock should be made extra strong. It is suggested that rudders should preferably be of the multi-pintle type and not of the "Simplex" or spade type as these are thought to give more trouble, if damaged, than the multi-pintle type.

A midship section of a typical icebreaker is given in Fig. 6.

SUGGESTED SCANTLING PARAMETERS

The parameters suggested are, in general, those that have been used, to a greater or lesser degree, on some of the existing icebreakers.

It can be seen the ratio s.h.p. divided by displacement has been used quite extensively, but subsequent research may show that the product of s.h.p. and displacement is a more desirable ratio for some of the items, and the use of this ratio is shown in the appendix at the end of the paper.

The parameters are suggested for the principal hull items for icebreakers operating in the polar regions.

For non-polar icebreakers it is suggested that the principles used for determining the scantlings of polar icebreakers be adhered to, but with a scaling down of constants

1. Shell ice belt at ends. Based on s.h.p. to displacement ratio, or alternatively, s.h.p. to beam ratio, with a small correction for frame spacing.
2. Shell ice belt over midship body. As a percentage of the above.
3. Remainder of side shell. As a percentage to (2).
4. Bottom shell clear of ice belt forward. As a function of length to breadth of vessel with a frame spacing correction.
5. Keel clear of ice belt forward. Say 20 per cent above Table 14 of the Rules. However, not to be less than say 0·06 in. thicker than (4).
6. Sheerstrake. As a function of length corrected for frame spacing.
7. Main frames (*see also* Appendix). Based on s.h.p. to displacement ratio, alternatively, s.h.p. to beam ratio. Small correction to be made for frame spacing and limits to be set upon the minimum and maximum spacing of frames. Section modulus of frames at ends of vessel not to be less than for main frames. Scantlings of frames in tween decks below desired waterline to be as for main frames. In any case frames not to be less than 75 per cent above Tables 12 and 13 of the Rules.
8. Intermediate ice frames. Scantlings, as for main frames and to be fitted over entire hull length. To extend to the nearest deck or stringer well above desired waterline. Frames at ends to extend down to and connect to centre girder. Elsewhere to be connected to tank margin.
9. Tween deck frames. To have a section modulus 75 per cent greater than Tables 12 and 13 of the Rules.
10. Web frames. Based on s.h.p. to displacement ratio, alternatively, s.h.p. to beam ratio, with adjustment for span of web frame and number of side girders supported. To be fitted at every 4th main frame space except at ends where they should be fitted at every 3rd main frame space. Should also bear some relationship to the section modulus of side stringers (11).
11. Side stringers. Based on s.h.p. to displacement ratio, alternatively, s.h.p. to beam ratio, with adjustment for span of stringer. Stringers should be placed not more than 4 to 5 ft. apart. Depth of stringer not to be less than $2\frac{1}{2} \times$ depth of shell frame.
12. Double bottom structure. Plate floors to be fitted on every frame. Number of side girders to be doubled above that required for a conventional vessel of equivalent breadth. Depth of double bottom increased. Thickness of floors, side girders, centre girder, margin plates and inner bottom to be increased above those required for a conventional vessel according to Table 6 of the Rules.
13. Deck plating. Thickness of deck plating in wings in way of the desired waterline to be a percentage of the adjacent shell thickness and in no case to be less than ·50 in. Remainder of this deck to be not less than ·40 in. thick. Other decks below this deck to be as for platform decks, or as appropriate, except the strake adjacent to the shell which is not to be less than ·40 in. thick.
14. Deck beams. Beams on the deck in way of the desired waterline to be on every main and intermediate frame. Scantlings of wing beams to be as for cargo deck beams +50 per cent. When calculating section modulus, spacing of beams to be assumed from main frame to main frame. Centre portion of beams on this deck to be as for wing beams but without the additional 50 per cent. Beams on intermediate ice frames not required for non-polar icebreakers. Remainder of deck beams below this deck to be as from the Rules +50 per cent.
15. Superstructures and minor bulkheads. Scantlings generally to based on conventional Rules except that a minimum thickness of ·25 in. be adopted. This is thought necessary because of the higher fatigue values experienced due to the rapid accelerating/decelerating forces acting when icebreaking.

It is, of course, important that all thicknesses should taper gradually throughout.

Finally, whatever parameter is decided upon in the determination of hull scantlings, it is suggested that the thickness of any web or other stiffening should bear some relationship to the adjacent primary member, for if a web or other similar stiffening is too thin relative to the shell or deck plating corrugation of the member will occur.

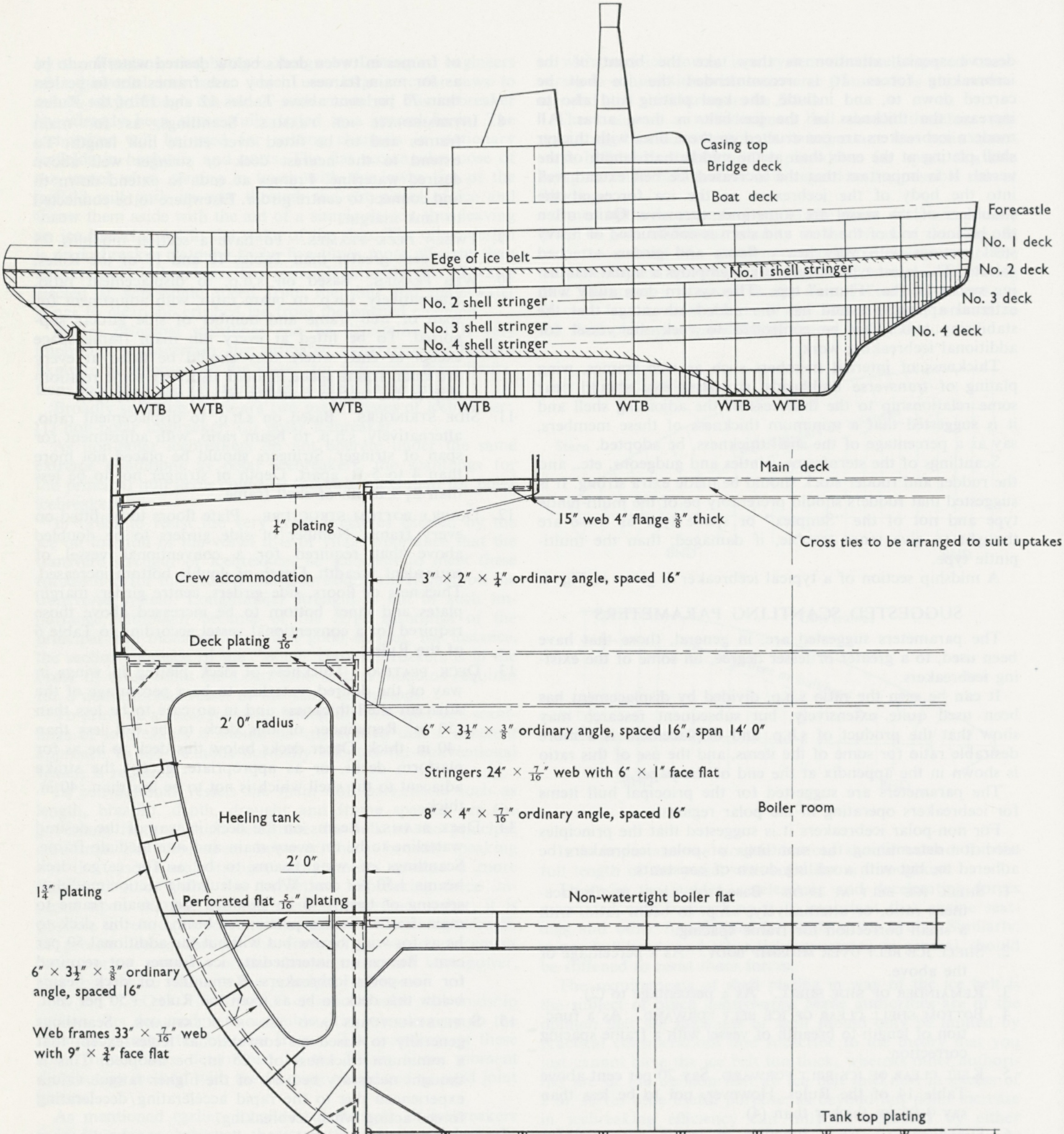


FIG. 6

Midship Section of a Typical Polar Icebreaker

QUALITIES OF STEEL

The hull plating of icebreakers is subjected to very severe impact forces as well as abrasive forces and it is important that a suitable type of steel is used, particularly in the region of the icebelt.

On the American "Glacier" and "Wind" class vessels H.T.S. quality steel, having a minimum yield strength of 44,000 lb./in.^{2} with a corresponding ultimate strength of 86,000 lb./in.^{2} and a Charpy V-notch energy quantity of 84 ft. lb. at 32° F. was used. Instances have been recorded of fractures in shell plating in American icebreakers having H.T.S. quality steel and accordingly proposals have been put foward to use H.Y. 80 quality steel in way of and below the icebelt for future American icebreakers. H.Y. 80 steel has very superior strength at very low temperature, i.e. at −50° F. the Charpy V-notch value is 133 ft. lb. whereas for H.T.S. at −50° F. the Charpy V-notch value is only 21 ft. lb. The exact physical properties for H.Y. 80 steel are not specified but the U.T.S. is believed to be over 100,000 lb./in.^{2} with a yield strength of 80,000 lb./in.^{2} (minimum). H.Y. 80 steel is believed to have been used on the American nuclear submarines.

High quality steels mean high capital costs and this factor should not be overlooked when choosing the type of steel to be used.

For recent icebreakers the Society has stated that for polar icebreakers, shell and deck plating over $\frac{1}{2}$ in. thick should be of grade D quality steel and for shell plating over 1 in. thick to be of grade E quality steel.

Det Norske Veritas Rules for icebreakers ask for shell and deck plating at the uppermost continuous deck to be of "W" quality steel if the thickness exceeds 12 mm., "D" quality if the thickness exceeds 25·4 mm. and "E" quality steel if the thickness exceeds 30 mm.

Table III gives thicknesses and qualities of steel used for several icebreakers.

WELDING

Icebreakers should preferably be all welded. Seams and butts, particularly at the ends of the vessel, should be buffed off smooth. This procedure is very important as it helps to reduce the sometimes very high friction forces prevalent during icebreaking.

Intermittent welding, particularly the structural members of the main hull, should be avoided. Scallops and notches should not be permitted and air and drain holes should be kept to a minimum.

The welding of icebreaker hulls demands very high quality workmanship and conditions. Welding practice borders on pressure vessel welding practice except that furnacing to anneal the complete shell is impracticable.

The maximum number of prefabricated sections as opposed to piecemeal erection should be used in order that assembly and welding sequences can be scheduled to utilise machine and downhand welding. Welding under low temperature conditions should not be permitted without pre-heating. Welded butts and seams should be examined with the use of X-rays.

The choice of plate edge preparation is important and should be chosen with regard to its position within the main hull.

OTHER ASPECTS OF ICEBREAKER REQUIREMENTS

1. Steering Gear

The manœuvrability of icebreakers is of prime importance. Also the pressures which the rudder, when working in ice, has to overcome are greater than those normally experienced by conventional vessels. It is usual, therefore, for the steering gears of icebreakers to be extra powerful and to incorporate additional safety devices against shock loading. It is suggested that steering gears for icebreakers be designed to put the rudder from hardover to hardover in 15 seconds whilst the vessel is going ahead at full speed.

2. Towing Notch

Icebreakers intended for towing have towing notches in the stern to accommodate the stem of the towed vessel. Sometimes these notches are lined with timber for extra protection. In addition, a towing winch or other suitable equipment is incorporated.

3. Sea Suctions

The icing up of sea suctions is a common hazard in icebreakers. Preferably, sea suctions should be placed just aft of the fullest section of the vessel or, if possible, as near to the propeller as practicable. This utilises the wash of the propeller in keeping the sea inlets clear of ice. Steam heating coils are often fitted around the sea inlet boxes and a system of baffle plates fitted in order to keep the apertures clear of any smaller pieces of broken ice that may find their way into the box.

4. Stepped Forefoot

This feature is usually incorporated in the smaller icebreakers and is fitted for a variety of reasons, the primary ones being that it prevents the bow from riding up completely on to the ice, if the ice is too thick to break, thereby producing dangerously low stability and it causes a secondary blow to the ice. It also helps steering ability. However, a stepped forefoot does not improve the deceleration forces already inherent.

5. Bilge Keels

These are avoided in icebreakers as they are usually torn off after their first commission. Retractable fin stabilisers have been fitted in the Canadian icebreaker H.M.C.S. *Labrador* and on the icebreaking passenger car ferry *William Carson*.

6. Stability

Because of their large beam, icebreakers are bad rollers and life on board can be very trying. This problem is alleviated to some extent by the very high standard of accommodation usually provided. The abundance of stability can have its advantages when the vessel's topsides become covered in ice, a hazard which for a normal vessel could spell disaster. As mentioned earlier good stability is necessary when the vessel rides up on to the ice.

7. Fire Precautions

The remoteness of duty and the possibility of complete isolation for many months puts the icebreaker in a very precarious position should fire break out. Unlike conventional vessels it is not quite so easy to send assistance to an icebreaker in distress and the standards of fire precautions should therefore be of the highest order.

8. Training of Crew

The training of personnel for duties on board icebreakers is given serious attention by authorities. Due to the exacting working conditions at very low temperatures, coupled with the prolonged periods away from base and other contacts

TABLE III

VESSEL	Dimensions L×B×d	Date of Build	Flat Plate Keel	Bottom Shell	Side Shell
D.E. "MOSKVA"	382′×80′ 6″×35′ 0″	1960	48 mm (XNT)	54 mm (XNT)	54/38 mm (XNT)
D.E. "KAPITAN BELOUSOV"	265′×63·65′×23·00′	1955	25 mm	28 mm (Coltuf)	28/30 mm (Coltuf)
S.S. "SWIATOWID"	145·5′×45·9′×—	1951	13 mm	18/24 mm	24 mm
D.E. "LABRADOR"	250′×63′ 6″×30′ 0″	1958	$1\frac{1}{4}$″ (Ducol)	$1\frac{5}{8}$″ (Ducol)	$1\frac{5}{8}$″ (Ducol)
S.S. "d'IBERVILLE	285′×66′ 9″×30′ 4″	1953	$1\frac{5}{8}$″	$1\frac{5}{8}$″	$1\frac{5}{8}$″
U.S.S. "GLACIER"	290′×74′ 0″×25′ 9″	1955	Not known	Not known	$1\frac{3}{4}$″ (HTS)
U.S.S. "WIND" Class	250′×63′ 6″×25′ 9″	1944	Not known	Not known	$1\frac{5}{8}$″ (HTS)
D.E. "WILLIAM CARSON"	325′×69′×19′ 3″	1955	·90″	1·13″	1·13″
D.E. "ODEN"	254′×63·6′×23·0′	1957	Shell contains steel of high impact value at low temperature		

"Ducol" is a weldable quality steel manufactured by Messrs. Colville's Ltd.

TABLE III

Upper Deck	Second Deck	Third Deck	Forecastle Deck	Other Structures	VESSEL
14 mm (XNT) stringers	14 mm (XNT) stringers	12 mm (XNT) stringers	12 mm (XNT) stringers	Forecastle side plating 15 mm (XNT)	D.E. "MOSKVA"
11 mm (Coltuf) stringers	13 mm	—	10 mm (Coltuf) stringers	Forecastle side plating 13 mm (Coltuf)	D.E. "KAPITAN BELOUSOV"
9 mm	8 mm	—	—	—	S.S. "SWIATOWID"
$\frac{1}{2}''$ (DW)	$\frac{1}{4}''$	$\frac{1}{4}''$	—	—	D.E. "LABRADOR"
$\frac{1}{2}''$	$\frac{5}{16}''$	$\frac{9}{32}''$	—	—	S.S. "d'IBERVILLE"
Not known	Not known	Not known	—	—	U.S.S. "GLACIER"
Not known	Not known	Not known	—	—	U.S.S. "WIND" Class
·38″	·41″	·31″	—	—	D.E. "WILLIAM CARSON"
			—	—	D.E. "ODEN"

(which may be high tensile, notch tough or a combination of both)

with the outside world, weaknesses of character soon become apparent. Some authorities base their training schemes on military ideas with regard to discipline and delegation of duty, but compensations in the form of a high standard of accommodation and recreation facilities usually offset these disadvantages.

9. Navigational Aids

In addition to the navigational instruments usually found on conventional vessels additional instruments are quite often fitted as standard for measuring external temperature, humidity, radio-active conditions in the atmosphere, echo sounders, rudder telegraphs, etc.

Because of any sudden accelerating or decelerating action from the icebreaker the risk of collision from a ship being towed is a potential menace. Good telephonic arrangements are therefore necessary from the icebreaker to the vessel being towed.

Usually an icebreaker can be manœuvred from several positions such as the wheelhouse, the bridge wings and a stern station, the latter being particularly useful when towing under difficult ice conditions. The latest icebreakers have a conning tower-cum-bridge fitted with all the important navigational and manœuvring instruments duplicated, so that the Conning Officer may navigate the vessel.

Helicopters are now quite often used and these have proved a tremendous asset in spotting the least course of resistance for the icebreaker to follow and for determining the ice conditions some distance ahead.

10. Launching Icebreakers

The weight per foot of an icebreaker compared with a conventional vessel of the same length is very high and calls for extra strong launch cradles with reinforced standing ways. Depth of water is also important, particularly over the way end, because of the large cut-up of the forefoot, resulting in very little displacement forward. The heavy launching weight also means a deeper submergence of the stern during launching again demanding a good depth of water. Some Scandinavian-built icebreakers have been launched with a steel pontoon fixed to the stern to give added buoyancy.

11. Nuclear Icebreakers

The choice of nuclear power for an icebreaker is a good one. Icebreakers have to operate for very long periods away from base with quite surprising differences of fuel consumption, depending upon conditions met, from voyage to voyage. Obviously, the longer an icebreaker can be in the icefields breaking ice, the better, as valuable time is always lost getting to and from base. The remoteness of duty also reduces the risks to densely populated areas on the vexed question of radio-active contamination, and the experience gained with nuclear propulsion under extreme weather and shock conditions would be very valuable. Icebreakers, whether conventional or nuclear, are not revenue producing vessels and are of very high capital cost. However, the introduction of a nuclear propulsion system would have a proportionally lower slice of the total capital cost as compared with a conventionally powered vessel.

The choice of nuclear or conventional power for an icebreaker depends upon the particular country's own strategic, trading or climatic conditions. This must limit the number of countries interested in the possibility of building a nuclear icebreaker and, to date, the only nuclear icebreaker in service is the U.S.S.R. *Lenin*.

The heat from nuclear fission could also be used to an advantage, in that it could be pumped overboard through long perforated pipes to form a "bubbler" system, thus melting to some extent the river ice.

CONCLUSION

The design and construction of icebreakers is one of the few remaining outlets in naval architecture where the more practical mind can find a good degree of freedom. Past experience gained breaking ice has always been the yard-stick by which any new ideas and conceptions, whether theoretical or practical, are measured.

Inevitably when experience plays a major role controversy reigns supreme, no less so than in the design and construction of icebreakers.

It is hoped that this paper will stimulate some controversy and constructive discussion and that it will serve to focus attention on this interesting and absorbing subject.

REFERENCES

1. "The Icebreaker", by I. V. Vinogradov. Schiff und Hafen (1958), January and March.
2. "Icebreakers and their Design", by Dr. Techn. Jan-Erik Jansson, M.I.N.A. European Shipbuilding Vol. 5 (No. 5 and No. 6).
3. "The Design and Building of Icebreakers", by A. Watson, M.B.E., P.Eng. The Institute of Marine Engineers Vol. 71, 1959.
4. "Development of Icebreaking Vessels for the U.S. Coast Guard", by Rear Admiral Harvey F. Johnson, U.S.C.G. S.N.A.M.E. Vol. 54, 1946.
5. Symposium on the Operation, Design and Construction of Icebreakers presented by various Authors at the Spring Meeting of S.N.A.M.E. 1959 Vol. 67.

ACKNOWLEDGMENTS

The photographs of the U.S.S.R. icebreakers *Moskva* and *Lenin* are reproduced by kind permission of "Motor Ship" and the small scale General Arrangement drawing of the U.S.S.R. *Moskva* is reproduced by kind permission of Wärtsilä-Koncernen A/B to whom this acknowledgment is made, with thanks.

APPENDIX

STRENGTH OF SIDE FRAMING

An investigation was made into the strength of main frames for several icebreakers classed with the Society, assuming the frames uniformly loaded between stringers, or similar horizontal supports, and stressed to 16 tons/in.^{2}.

Assuming $B.M. = \frac{WL}{12}$ the corresponding pressures were calculated and are tabulated below.

In general, icebreakers are usually compared on a horsepower per ton of displacement basis. It is suggested that this in itself is meaningless, e.g. *Lenin* has a h.p./ton ratio of 2·75, but a small tug of 100 tons displacement and an engine horsepower of 275 would also give the same ratio.

As an alternative, therefore, it is suggested that icebreakers be compared on the product of displacement and horsepower, probably of the form,

$$SHP \times L \times B.$$

Quantities of $SHP \times L \times B \times 10^{-6}$ are given for each of the icebreakers tabulated, together with the actual section modulus of main frames.

From the above assumptions $I/Y = \frac{144\ Pl^2s}{16 \times 2240}$ or $0{\cdot}00402Pl^2s$

where P = ice pressure in lb./in.^{2}.

l = span of frames from stringer to stringer or stringer to deck in feet.

s = frame spacing in feet.

It can be seen from above that frame scantlings have no bearing on size of ship.

To overcome this it is suggested a factor "K" be introduced dependent upon $SHP \times L \times B \times 10^{-6}$.

The suggested basic formula would then become $I/Y = K \times 0{\cdot}54 \times l^2$ where K is as follows:—

$SHP \times L \times B \times 10^{-6}$	K
700 and over	4·05
600 ,, ,,	3·65
500 ,, ,,	3·25
400 ,, ,,	2·85
300 ,, ,,	2·45
200 ,, ,,	2·05
100 ,, ,,	1·65

The values of K for each icebreaker have been calculated from the above formula and are given in the Table together with the corresponding permissible ice pressure.

Name of Vessel	Actual $\frac{I}{Y}$ of frames (in.^{3})	Actual ice pressure (lbs./in.^{2})	$SHP \times L \times B \times 10^{-6}$	$\frac{I}{Y}$ from formula (in.^{3})	Corresponding pressure (lbs./in.^{2})
MOSKVA	79·4	540	710	61·5	416
NEW TONNAGE BY G.G.M.	66·0	491	705	54·7	405
JOHN A. MACDONALD	45·0	277	365	44·3	272
d'IBERVILLE	45·0	131	311	86·0	248
ABEGWEIT	21·0	82	300	84·8	264
ADMIRALTY	83·0	243	251	78·0	228
WILLIAM CARSON	21·0	262	244	19·3	240
KAPITAN BELOUSOV	36·0	377	185	19·5	204
ODEN	36·0	377	186	19·5	204
LABRADOR	72·0	208	172	67·0	195
MONTCALM	17·0	198	53	14·3	170
PERKUN	15·4	240	27	14·3	222

As can be seen from the Table there is a reasonable comparison between the calculated ice pressures and the actual, except for the *Abegweit* and *d'Iberville* which would seem to indicate that the scantlings of the main frames for these vessels are insufficient for polar icebreaking.

PRINTED BY LLOYD'S REGISTER OF SHIPPING
AT GARRETT HOUSE, MANOR ROYAL
CRAWLEY, SUSSEX, ENGLAND

Lloyd's Register Staff Association

Session 1964 - 65

Paper No. 2

Discussion

on

Mr. L. J. Crighton's Paper

ICEBREAKERS—THEIR DESIGN AND CONSTRUCTION

LLOYD'S REGISTER OF SHIPPING

71, Fenchurch Street, LONDON, E.C.3

The Author of this paper retains the right of subsequent publication, subject to the sanction of the Committee of Lloyd's Register of Shipping. Any opinions expressed and statements made in this paper and in the subsequent discussion are those of the individuals.

Discussion on Mr. L. J. Crighton's Paper

ICEBREAKERS—THEIR DESIGN AND CONSTRUCTION

Mr. C. J. G. Jensen

It is clear that the formulation of the Rules for icebreakers must be based very largely on the results of experience on the success or otherwise of the forms and structural arrangements of early types.

The simulation of ice conditions in model tests has been attempted, but so far has met with little success largely because no material has yet been found which satisfies the similarity requirements for transition from model measurements to full scale, i.e. the ice substitute used in model tests fails to satisfy simultaneously all the requirements of rigidity, coefficient of friction in wet and dry states, specific weight, etc. Also, it is impossible to represent the characteristic behaviour in the ice breaking of pack ice ridges and sheets of snow of various strengths, etc.[1]

The Author states (page 13) that it can be seen that $\frac{\text{SHP}}{\triangle}$ has been used quite extensively as a parameter for hull scantlings. This is not obvious and perhaps the Author would explain where this comes from as, to me, his own proposal, given in the appendix, to use SHP $\times \triangle$ appears more logical.

The Author mentions the disadvantage of the full lined spoon shaped bow of the *Murtaja,* built 1890, in making progress in snow covered ice. The records show that the ice accumulated below her bow to an extent that at times she was pushing along a field of ice 100 ft. long. In more modern times under similar conditions, reports from North America talk about pushing flows of snow covered ice several hundred yards in extent. The remedy, as the Author points out, is to have sharper less convex bows.

The Author points out the advantage of twin over single bow propellers in estuary type icebreakers. In fact, it is now general practice for Baltic icebreakers to have twin bow propellers, and it should be mentioned that inward compared with outward rotating screws give appreciably better washing of the bows, and facilitates disposal of broken ice. Manœuvrability with four screws is such that a vessel can move directly sideways in open water. Incidentally, one of the reasons that Polar icebreakers do not have bow propellers is that neither propellers nor shafts can be built strong enough to stand the loading involved. In this connection, it is interesting to note the adoption of a water jet manœuvring system forward in the new icebreaker recently ordered in Canada.

The Author's stipulation that the forward body should be repeated in the after body as much as possible requires some clarification, and in fact the opinion of experienced operators is that the stern should be more rounded than the bow in order to give the propellers the maximum protection, and also so that the icebreaker would leave a clear channel behind her. Further, there should be sufficient displacement volume astern so that the stern will not be pressed down into the water if the bow rides on the ice.

The question of providing tumblehome is perhaps controversial. Some operators contend you cannot build in sufficient tumblehome to avoid damage on coming alongside to free a trapped vessel, and the tendency is to dispense with tumblehome with a resulting gain of valuable deck space.

The Author mentions the USCG *North Wind* class on page 12. He does not comment on the efficiency of the diagonal bracing compared with the system of webs and stringers favoured by other designers. Finnish designers distrust the truss system on the basis that the strength depends on the strength of the strut brackets which are more liable to complete collapse than is the case with webs and stringers which they claim can deform plastically without the immediate fear of complete collapse.

In the older riveted icebreakers shell rivets had constantly to be renewed owing to the scrubbing action of the ice on the points and welding was welcomed as the answer to the problem. However, it was found that the friction of the ice also rubbed off protective paints, and the continuous derusting process accelerated the corrosive action even on welds which had been buffed smooth. The high percentage of salt and oxygen in cold water, together with air bubbles formed under the hull by bow propellers further accelerated the corrosion of welded butts and seams. In practice, corrosion more than $\frac{1}{4}$ in. deep has been experienced in one year in the Arctic. Research showed that the use of low hydrogen electrodes, required to give crack-free weld metal on the special quality steel shell plating, was the principal source of the trouble. When low hydrogen electrodes sufficiently electro positive as to prevent the deposited metal becoming anodic were used, no more trouble was experienced. The special anti-corrosion electrodes developed by the Swedish firm of ESAB contain some 0·8 per cent copper in the deposited metal.

Mr. J. B. Davies

Mr. Crighton has given us an extremely interesting paper on a subject which only a few Surveyors get much of an opportunity to see either the plans or the vessels in operation.

In his introduction, he implies, perhaps inadvertently, that icebreakers were a relatively modern invention, due to the expanding population of the earth. This is a simplification of the problem, since there are some countries, such as Finland, whose survival in the winter depends on sea communications. It is not merely a coincidence that Wärtsilä Koncernen Sandvikens Skeppsdocka have built more icebreakers than any other builder.

I think the Author is in some confusion regarding the types of icebreakers, since on the first page he divides them into (1) Harbour and Estuary and (2) Polar, whereas on page 12 he remarks that "broadly speaking there are two main classes of icebreaker (1) non-polar icebreaker (2) polar icebreaker". I would suggest that there are really three classes. Firstly, those breaking ice in harbours, secondly those in non-polar waters, such as the Baltic, and thirdly the polar icebreakers operating on the Arctic coast of Russia and in the Antarctic. There is a very much bigger difference between the harbour icebreaker and the non-polar icebreaker than there is between the non-polar and the polar icebreaker. The harbour icebreaker is a glorified tug with extra strengthening, whereas the non-polar icebreaker is, in design details, barely distinguishable from the polar. Canadian icebreakers mentioned on

[1] Landtman—Technical Aspects of Large Modern Ice-Breakers.

page 6 have, in the past, been somewhat of a bastard design, since they are not purely icebreakers but are also store carriers; their block coefficient is therefore higher than a pure icebreaker.

When dealing with suggested scantling parameters, the Author mentions the ratio shaft horsepower divided by displacement, but I must say I have always found it rather difficult to see the reason why this should be accepted. If you double the s.h.p. and double the displacement, the ratio remains the same but the type of ship changes very much. I feel that his alternative proposal of s.h.p. $\times$ displacement is much more realistic. I would like to look into this further, because I think the time has come when the Society should produce Rules for icebreakers.

I well remember the first time I had to approve the plans of an icebreaker some 14 years ago. This was the *Voima* which, while not being built to class, was to be approved by the Society. I remember looking at the 1 in. shell plating and thinking that this was fine in association with, if my memory serves me correct, 15 in. channel frames. I looked a bit further on the plan and saw that there were 15 in. intermediates in addition! As the only class notation was to be Strengthening for Navigation in Ice, I had no computation for signing the plans.

Mr. D. Gray

The following points are largely in amplification of certain sections of the paper rather than criticisms or comments. It would be as well to state at the outset that most of the information has been gathered from papers published by others but notably by Josef Stiglitz of Siemens Schuckertwerke who has been involved with icebreaker propulsion machinery for many years.

Regarding ice breaking, it may be of interest that during trials in the Arctic the *Moskva* was able to plough continuously through an ice layer of between 2 and 3 metres in thickness and also overcame ice walls 5 to 6 metres thick by charging.

The heeling tanks to which reference has been made—the heeling frequency is very low. The period of oscillation is about 0·5 to 2 seconds, yet heeling angles of up to $\pm 10°$ have been recorded.

Polar icebreakers are built exclusively with after propellers since the possible damage to forward propellers would be too great in such craft. In polar icebreakers the number of after propellers is usually 1, 2 or 3 the number being governed by the driving power and the ship's dimensions, i.e. by the size of the propulsion motors, the space available in the after body for accommodating them and by the maximum permissible propeller diameter. For operational reliability three propellers provide greater standby facilities than two.

With three propellers a $\frac{1}{4} : \frac{1}{2} : \frac{1}{4}$ distribution of power is chosen rather than $\frac{1}{3} : \frac{1}{3} : \frac{1}{3}$. With such an arrangement the diameters of the outboard propellers, which are more exposed to damage, can be kept smaller, whilst the main power is transmitted to the centre propeller which is in a more protected position. In addition, steering is more efficient as the rudder blade is located behind the centre propeller.

As regards propulsion machinery, both diesel engines and steam turbines have unfavourable torque/speed characteristics and possess inadequate starting torque to be considered for propulsion purposes. In addition, the reduction gearing which would be necessary with turbines may not be able to accommodate the shock loads caused by propellers striking the ice. These are the principal reasons for the adoption of electric propulsion. The first cost of such machinery is higher and a certain amount of power loss is inevitable, due to the double power conversion, but the advantages are so great that electric drive has been chosen almost without exception in recent years for all icebreakers.

Also, with the exception of the *Lenin*, all the large icebreakers built in recent years have had d.c. diesel-electric propulsion. The *Lenin*, of course, has d.c. turbo-electric equipment.

With all icebreaker drives control is generally of the Ward Leonard type.

Reversal of the propeller can be a frequent operation in an icebreaker and poses problems for the designer of the machinery since the reverse power, which occurs when reversing the propeller, must be kept as low as possible.

The kinetic energy of the ship causes the ship to continue moving for a considerable time after the driving power applied to the propeller has been removed. If the propeller were to be uncoupled from its motor in this case, the flow conditions can give rise to a propeller speed of 60–70 per cent of its initial speed before uncoupling. A further reduction in speed is only possible by braking the propeller for, within this speed range, the flow conditions due to the speed of advance, cause the propeller to act as a turbine. The time taken for the propeller to be retarded to zero speed depends very much on the available braking torque. Tests carried out have shown that braking of the propeller to standstill has little effect on the retardation of the ship. The only way of effectively stopping the ship within a short time is to reverse the propeller. During this rapid reversing the transient propeller torques in the "reverse" speed range are considerably higher than their steady state values. This is obvious when one considers that the propeller pitch is directed against the direction of flow of the water for some time.

Both in the case of direct drive diesels and diesel-electric drives the compression of the diesel is utilized to brake the propeller during reversing. Added to this in diesel-electric drives are the losses in motors and generators (which may be even higher than at rated load) so that from this fact alone somewhat higher braking torques can be obtained than with direct diesel drive. During the braking operation the propeller motor becomes the generator and the generator drives the prime mover and this may of course lead to overspeeding of the prime mover. The degree of overspeed depends on the magnitude and duration of reverse power, the moment of inertia of the prime mover and the time taken to shut off the fuel.

Diesels can absorb up to 20 per cent of their output as reverse power (acting then as compressors) but turbines can absorb very little. It is not surprising, therefore, that, as Russian sources reported, a reversing time of 35 seconds from full ahead to full astern had to be provided for the *Lenin* in order to prevent turbine overspeed.

Fig. 1, derived from oscillograms, shows the load conditions during reversal of the centre propeller of the *Moskva*, which is fitted with d.c. diesel-electric drive with Ward Leonard control.

Shock loads on the propellers, e.g. the propeller striking ice, can cause even more severe conditions. Fig. 2 illustrates the blocking of the port propeller of the *Moskva* by ice.

It can be seen that propeller torques of up to 2·3 times rated torque—referred to rated torque under ice flow conditions—give rise to generator torques of about 115 per cent.

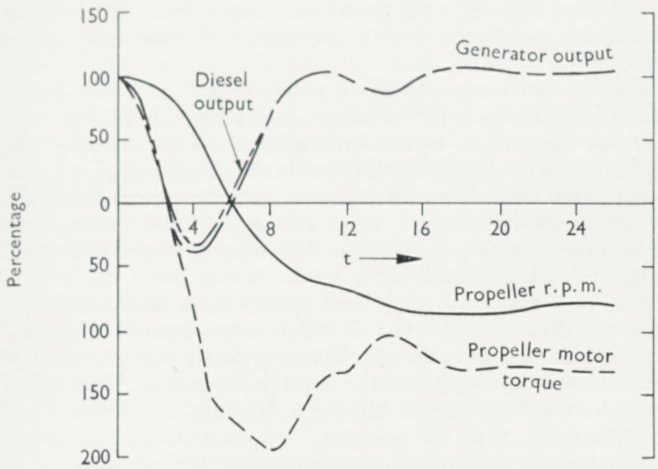


FIG. 1

Reversing the centre propeller on the icebreaker *Moskva*.

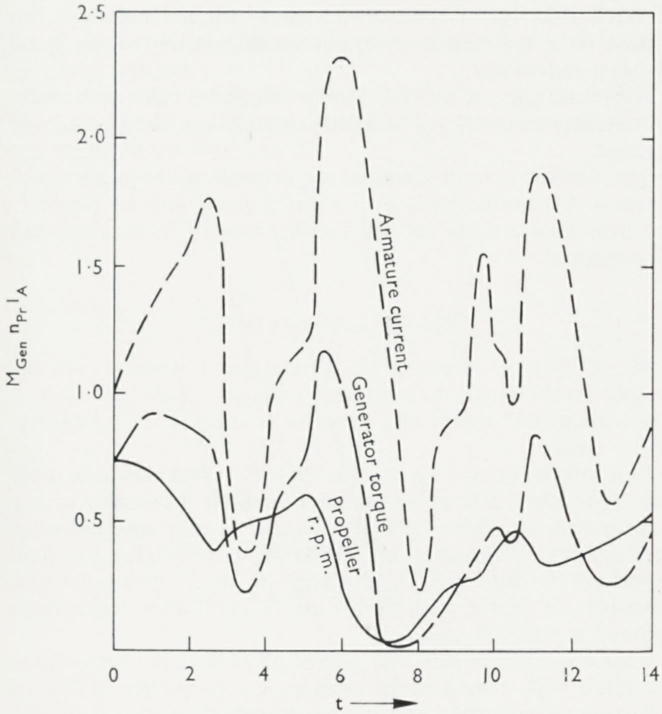


FIG. 2

Icebreaker *Moskva*—blocking of the port propeller.

Such torque peaks are transmitted to the diesels but can be reduced somewhat by suitable circuit and machine design. However, since the magnetic inertia cannot be completely compensated the magnitude of the transient loads depends on how rapidly the torque is developed at the propeller.

Also it is normal with the electric system to limit the propeller motor torque so that the propeller and shafting are not endangered. The general requirement is limitation to 200 per cent rated torque for after propellers and for forward propellers about 300 per cent rated torque.

Both of these problems are usually solved by giving the propulsion system characteristics that lead to a reduction in voltage, and consequently a reduction in propeller speed, with increasing propeller torque.

The inertia, however, has the effect that in the event of shock load on the propeller motor, the output required from the generators increases and does not drop to the steady state value until after a short time delay. A rapid rise in load is followed by an almost equally steep dip in generator output.

There is a further factor which may be due to hydrodynamic effects. Oscillograms show that a considerable dip in propeller power input very often precedes shock loads. This may be due to a change in flow conditions just prior to the ice entering the propeller.

Both of these phenomena—the dip in propeller power input shortly before shock loads and the following load peak—can lead to very severe load conditions for the generators and, therefore, for the diesel engines.

One of the prime requirements for icebreakers' machinery is that it must be capable of supplying as much power as possible at all times. Only thus is it possible to maintain optimum ship's speed in ice and thus carry out efficient ice breaking. In order to obtain optimum generator output, dips in the speed of the diesels must be kept to a minimum under the fluctuating load conditions described above. The magnitude of the reduction in diesel speed with rapidly increasing load is largely governed by the speed of response of the governor, the setting for the fuel injection and, in the case of supercharged engines, the speed characteristic of the exhaust turbine supercharger. Nowadays, high speed governors are available; also it is generally possible to arrange the fuel injection limit to allow a value of, say, 110 or 120 per cent since such a quantity of fuel is injected for a few seconds only. It is largely for this reason that non-supercharged diesels are largely used in ice breakers. With supercharged diesels as a result of the severe and rapidly fluctuating load conditions the exhaust turbine does not reach its full speed and the load capacity of the engine is reduced.

Some improvement in the load conditions for the diesels can be brought about by coupling each diesel with two generators each feeding into different propeller circuits. The probability of each propeller and associated generator being subjected to shock loads simultaneously is slight. In this way the load fluctuations on the diesels can be reduced to about 50 per cent during ice breaking although double the number of generators is required for a given number of diesels plus double the amount of switchgear and cabling.

Some overload conditions for the electrical machinery which has been specified in the past is given in Table 1.

Time	Generators		Motors	
	Overload (per cent)		Overload (per cent)	
	Case 1	Case 2	After Propellers	Forward Propellers
5 hours	10	30	10	30
2 hours	25	75	25	75
30 min.	50	150	50	150
5 min.	80	240	80	240
5 sec.	100	300	100	300

TABLE I

Some overloads called for in electrical machinery in icebreakers.

Mr. R. G. Lockhart

It is always encouraging when a younger member of the surveying staff presents a paper to the Association and there is little doubt that the Author has endeavoured to enlighten himself on the design of icebreakers. In this respect he has summed up his findings in a comprehensive manner.

I think, however, it would be unwise to ask for any clause to be inserted in the Rules regarding hull form. Icebreakers have been functioning for some time and the raised forepost, the convex waterline, and the inclined sides are just about as common as a funnel.

It is also perhaps worth remembering that the *Perkun* is the only ship built to the Society's Rules with icebreaker in the class.

Since the Author has decided to concern himself with power in relation to scantlings it would be reasonable to state the precise horsepower to be used. Referring to Table 1 it may be noticed, in the case of *Ernest Lapointe* and *William Carson,* both presumably with one screw forward, the total horsepower does not include the forward shaft horsepower, while the *Thule,* also having one screw forward, has this included in the total horsepower. In all other cases of ships having two screws forward the shaft horsepower of these appears in the total. The normal practice in dealing with ice strengthening is to use the shaft horsepower for the ahead condition and it is difficult to see that this need be departed from.

There are one or two discrepancies in the lengths between Table I and Table III and the Register Book, e.g. *Moskva* length B.P. Table I 368 ft. 8 in. Table III 382 ft. and Register Book 347·5 ft.

It is concluded that since s.h.p. to displacement has been suggested as a basis for shell thickness that example has been made to justify this, reference to Table I makes such a comparison difficult, e.g.: —

Ship	*Length*	*S.h.p./t*	*Side shell*
Perkun	160 ft.	1·88	·90
William Carson	325 ft.	1·30	1·13
Moskva	368 ft. 8 in.	1·43	2·12–1·68

It would appear that the Author has himself some doubts about this parameter as he then states that probably s.h.p. to beam might be better. This would give some more reasonable basis only because L/B is reasonably constant but if shaft horsepower to length is used the above ships then can be compared as

Ship	*S.h.p./L*
Perkun	20·5
William Carson	31·0
Moskva	60·0

A quick analysis of shell based s.h.p./L and adjusted for ice pressure would suggest that shell thicknesses related very closely to those given in Table III can be obtained. To quote four cases over the range by this method the following comparisons are obtained: —

S.h.p.	*Ship*	*Length*	*Thickness based on s.h.p./L*	*Actual thickness*
3300	Perkun	160 ft.	·90	·90
6950 aft only	Oden	253 ft.	1·09	1·18–1·07
21,000	Glacier	296 ft.	2·12 × ·8 = 1·72 H.T.S.	1·75 H.T.S.
22,000	Moskva	347·5 Reg. Book	2·07	2·12–1·50

Having obtained the maximum for the ice belt, the remainder appears to bear a reasonably constant relationship to this.

The method suggested for deriving frame scantlings leaves much to be desired. For example, in the case of the *Oden* the formula suggests a section modulus of 54 per cent of the frame actually fitted. Amidships in this vessel the stringers fitted based entirely on ice pressure results in values not much in excess of 100 lb./in.^{2} while the web frames which form some compensation support to the stringers could only have a value of about 20–50 lb./in.^{2}.

The web frames, stringer and intermediate frames together with the shell plating which is vitally important when dealing with thicknesses already mentioned forms a composite grillage system and surely can only be considered as such. The double bottom structure suggests transverse framing only. Plate floors on alternates with an adequate longitudinal system would surely present an acceptable alternative.

Under steering gear it should be forgotten that the maximum rudder angle will not be required. Gears designed to produce the normal torque very often produce a hard over to hard over in 15 seconds. If extra torque is desired this should be a requirement without much relation to the speed of helm movement.

It would appear, as the Author suggests, that some additional research work is necessary before any finality can be reached.

The Author is to be thanked for presenting the paper which forms a reasonable basis as a starting point and no doubt in the near future rules for the construction of icebreakers can be produced.

Mr. A. Lindqvist

Mr. Crighton's paper gives a very good summary of the recent development in icebreaker design. There are only a few comments I would like to make relating to the conditions in the Baltic.

It is probably not correct to divide icebreakers into only two types, the difference between a harbour icebreaker of say a maximum of about 2,000 b.h.p. and usually one propeller and a Baltic icebreaker of 10,000 to 12,000 b.h.p. of four propellers is too big. A division in three groups would probably be better with Baltic or Great Lakes icebreakers forming a separate group.

I believe that the fact that almost all new Baltic icebreakers are fitted with two inward turning bow propellers is due to the easier manœuvring and by the propeller's wash very much decreasing shell/ice friction. An icebreaker in the Baltic is very often required to cut free and tow merchant ships stuck in the ice and there the manœuvring ability is, of course, of prime importance.

The angle between the stem and the waterline varies between 23 and 25 degrees on the Baltic icebreakers and between 26 and 30 degrees on the polar icebreakers, it would be interesting to know where an angle as large as 35 degrees has been used.

One of the reasons for the large beam used is to be able to break a channel for the cargo ships following the icebreaker, on the other hand more power is needed, in about direct proportion to the beam. The Author's remark "the broader the vessel the easier it can break ice" is therefore not quite understood and it would be interesting to know where L/B ratios of about six have been used.

When the heeling tanks are used it is in order to free the ship's side shell from ice and to reduce the high statical friction between dry ice and the steel plate to the friction between wet ice and steel, the heeling is usually 5–8 degrees. Trimming tanks are mainly used to obtain the best icebreaking trim and not to free the ship.

The diameter of the bow propellers has been slightly decreased on recent ships in order to avoid them being stuck in ice, their efficiency going astern is not considered as important. The aim is to be able to break the ice without making attacks as these always cause difficulties for the merchant ships following the icebreakers. A very common type of ice-damage is "contact with icebreaker stern". The main purpose with the bow propeller is as mentioned to decrease the friction and not to reverse the ship. If a bow propeller could be built strong enough it would probably be very useful also on polar icebreakers.

It would be interesting to know if Kort nozzles have been used on any merchant ships in ice. The small tugs where these nozzles have been fitted usually do not move in any normal winter ice.

I presume that the Author means pitching and not rolling in the case of the German jumping icebreaker system used on *Josef Langen*.

To the figures for the strength of ice can be added a diagram showing the tensile strength depending on salinity and temperature (*see* Fig. 3).

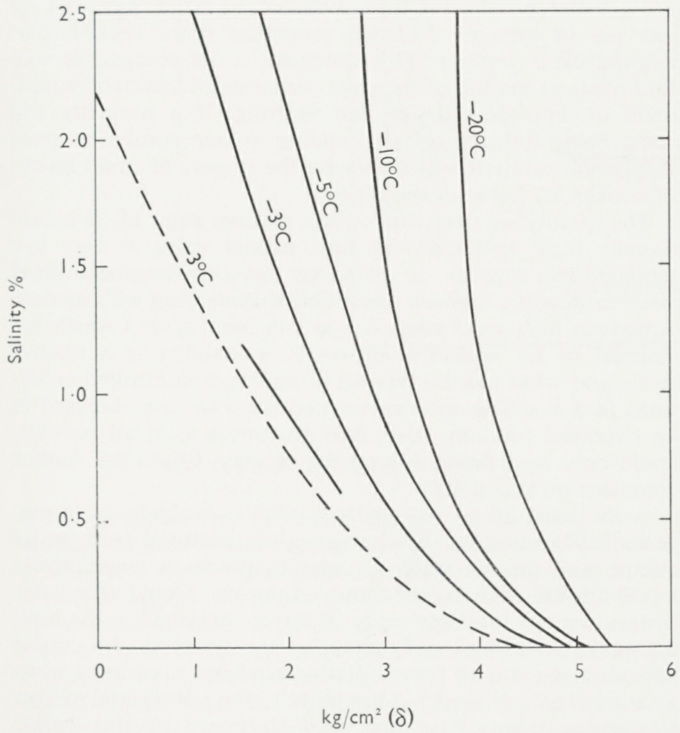


FIG. 3

The base for the strength calculations are given by the builders to be 300 t/m.² for the shell and 200 t/m.² for the framing on the Karhu class icebreakers and 1,000 t/m.² for the shell and 800 t/m.² for the frames forward, 500 t/m.²–400 t/m.² amidships and 750 t/m.²–600 t/m.² aft for the Moskva class icebreakers, calculating with a yield point of 26 kg./mm.² for the steel.

I cannot see what bearing the hull form has on the friction between the hull and the ice, the friction is probably much more influenced by the different ice conditions.

A theoretical calculation of the icebreaker forces and the power needed for icebreaking is very difficult, the sea ice is definitely not a homogeneous medium and the power is influenced by the varying coefficients of friction.

The main reason for the extent of the ice belt is, of course, the simple fact that 9/10 of the floating ice is below water and as the height of the ridges in pack ice can be quite high they are deep underneath the surface also.

A few remarks regarding the suggested scantling parameters:—

Shell ice belt: some harbour tugs should have bigger shell thickness than the Moskva type icebreaker if the shell thickness is not related to length.

Main frames: why could these not be based on specified loads in tons/m.² based on class? The minimum spacing for accessible construction should probably be used.

Regarding the welding of icebreakers mention could be made of the importance of using corrosion resistant electrodes. The anti-corrosive paint is, of course, worn away very quickly and the welds exposed to the sea water all the season.

The arrangement of sea suctions is shown in Mr. Landtman's paper mentioned in the references below. This paper contains very much of the present views on modern icebreakers in Finland.

Probably the oldest paper about this matter "Steamers for Winter Navigation and Icebreaking" was read in 1889 by R. Runeberg before the Institution of Civil Engineers and we are grateful for Mr. Crighton's paper in a field where only a few papers have been read since 1889.

REFERENCES:—

I kamp med Östersjöns isar, Henrik Ramsay, 1947. (The Fight against Ice in the Baltic.)

Om galvanisk korrosion i svetsfogar vid svetsade fartyg, V. Valanti, Scandinavian Shiptechnical Meeting, 1960. (The galvanic corrosion of welds in welded ships.)

Technische Gesichtspunkts über moderne grosse Eisbrecher, Christian Landtman, Schiffbautechnische Gesellschaft, Nov. 1961.

Havsisens hållfasthet, Ilmari Sala, Teknisk Tidskrift, 1959. (Strength of Sea Ice.)

MR. S. J. TORNQVIST

Mr. Crighton is to be congratulated on a clear and determinative paper. The icebreaker is a very special construction in shipbuilding, as the Author also intimates, and there is not much literature and test reports available. I would like to make a few comments on icebreaker propellers in particular.

For the usual diesel-engined harbour icebreakers, the variable pitch propellers are probably the best solution from the manœuvring considerations as main engine weardown is kept to a minimum. The Voigt-Schneider propeller arrangement is also satisfactory for the same reasons but to the writer's knowledge only one icebreaker in Finland is so equipped so that it is premature to pass an opinion at present.

At trials with twin bow and twin stern propellers type icebreakers it has appeared that the bow propellers have to rotate inwards. Thus an effective washing of the sides at 0·25L from the stem is achieved while on the other hand, if the propellers are rotating outwards, the stream of water is pressed down under the keel. The aft propellers, however,

should rotate outwards in order to make the channel as free from ice as possible.

As regards the shape of the stem of type 1 icebreakers (harbour icebreakers) Professor K. Albin Johansson recommends a concave form, as shown in Fig. 4, in order to get the icebreaker to cling tight on to the ice edge in the channel.

Further he recommends $C_B = 0{\cdot}43 - 0{\cdot}45$ at CWL on the same type of icebreaker and a rather big aft trim.

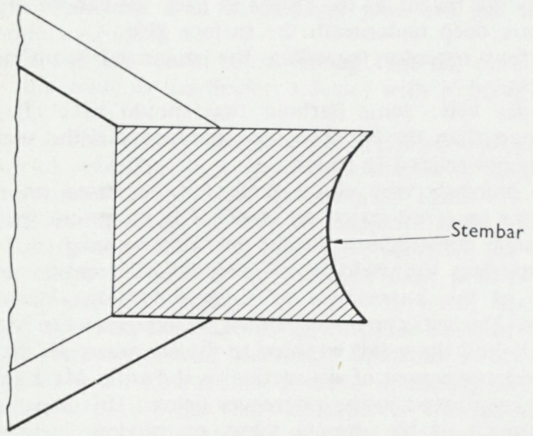


FIG. 4

MR. R. J. C. DOBSON

This is an interesting paper in many ways, not in the least because it seems to point to a continued change in the Society's policy. From the passive awaiting of developments to taking an active part in the breaking open of new fields. It is noted with some reserve, however, that the Author wishes to write a clause on the hull form in the Rules. This clause will have to be very loose if it is not going to restrict designers unduly. If the Author's suggestions on hull form are followed, it would immediately disclassify the Canadian icebreakers, which, with their high block-efficient (see Table I) cannot possibly fulfill the requirements. It would appear, therefore, that a new class would have to be introduced, that of "Icebreaker" as distinct from "Strengthened for Nav. in Ice".

Another minor criticism is that Table I has not been used to illustrate some of the points made in the text. Where is the approximate border line between Type 1 and Type 2? Does the L/B ratio indeed tend to increase to 6? The great merit of this paper seems to this writer to lie in the appendix in which the Author suggests a new numeral which is logical from the point of view of design as well as for assessing scantlings, something on the lines of the numeral "N" for tankers. Comparing the I/Y formulæ in the two columns the constant 0·54 has probably been arrived at by multiplying the constant 0·00402 by $1{\cdot}33 \times 10^2$, the usual frame spacing of 16 in. the Author mentions on page 11. It would seem preferable to leave the frame spacing in the formula and allow the builder to choose his own spacing. However, the K-value appears thus to be another way of writing $P \times 10^{-2}$, in which P is the ice pressure. There should, therefore, be a close agreement between the K-values and the corresponding pressures in the Table on page 19. Taking, for instance, "New Tonnage" the numeral is 705, the corresponding ice pressure is 405 lb./sq. in. and the K-value is 4·05. It is therefore surprising to find discrepancies as in the case of the *Abegweit* with a numeral of 300, a corresponding ice pressure of 264 lb./sq. in. and a K-value of 2·45, but even more so in the case of the *Perkun* where the figures are 27 and 222 respectively and a K-value presumably far less than 1·65. The Author's comments will be appreciated. It would also be of interest to know how the actual ice pressures are arrived at. Have they been calculated with the formula, using the known ship's data or have the actual ice pressures been quoted by the builder? If the latter is the case it might be argued that the *Abegweit* and the *d'Iberville* are not insufficient for polar icebreaking but are greatly overpowered for the job they have to do.

MR. J. GUTHRIE

Mr. Crighton is to be congratulated on a most interesting and well informed paper on a subject with which few of his colleagues can have a very deep knowledge.

There are a few points, however, which are not self-evident in the paper, and perhaps the Author could enlarge on them.

In Type 1, i.e. icebreakers suitable for cutting ice in more temperate zones, the bow has rather full lines and little cutwater. Why do designers not use the old-fashioned bar stem and bar keel, suitably reinforced with keelson and sister keel? Surely this design would have far greater cutting effect than a flat bottom, as well as providing a more solid mass to take the shock?

At the bottom of page 8, it is stated that 4-bladed propellers are a better proposition than 3-bladed, as larger pieces of ice can get in between 3-bladed propellers more readily, thus causing blade fracture. This statement is not compatible with that made at the top of the page concerning Canadian Department of Transport design for Shafting. If a propeller will resist being brought up all standing in one revolution from full speed, surely it will withstand the impact of small blocks of broken ice between the blades.

The quality of steel for ice-belt plating, page 15, is exceptionally high, and the very high impact value at very low temperature suggests a balanced carbon-manganese-nickel steel, or possibly a boron steel. This is in keeping with modern American high-yield steels (up to 140 tons/sq. in.) which are claimed to be weldable. However, weldability is a relative term, and what can be welded in optimum controlled conditions in a machine shop is not necessary so in a shipyard in an overhead position. Also, heat treatment, if at all possible, could only be rudimentary on the slipway. Could the Author comment on this point?

Is the icing-up of sea suctions such a problem as is suggested? The modern diesel engines use a closed fresh water circuit, and the sea water circulating system is consequently more flexible than is commonly supposed. Could this latter system not use the large body of water contained in the heeling tanks as a heat sink, much as the water in the double bottom tanks is used for circulating auxiliary machinery when a vessel is in dry dock? Alternatively, the continental system whereby a whole bay, port and starboard in the double bottom, could be opened to the sea, with continuous grills on bottom, could be used as an intake for the various sea injection valves.

This bay could hardly choke up for its full width, but as an added precaution the circulating water overboard could be by-passed into this bay to keep it clear.

It would be unfair to ask the Author for particulars of the behaviour of the nuclear reactor fitted in USSR *Lenin*, as this information would hardly be volunteered by the Russians.

but I cannot imagine a type of vessel less suitable for use as a prototype. Of all the delicate machinery fitted in a nuclear vessel, the reactor is perhaps the most sensitive, for while modern conventional machinery uses remote control to a considerable extent, the reactor requires remote controls to control remote controls; it needs remote controls to the second power, so to speak. Therefore, these exceptionally refined instruments are very vulnerable to the violent shocks sustained by the icebreaker in attacking the ice at full power and being brought to a sudden halt. Apart from these, however, there is the question of the actual components in the reactor shell: fragile and temperamental metals, "egg-shell" thick welds, minute clearances, coupled with the ever-present risk of leakage in the primary circuit. How do they stand up to icebreaker service?

Finally, thumbing through my collection of shipping oddities, I find that even icebreakers can be converted on the do-it-yourself plan, and I enclose a sketch of ice knife and ice fins built around the propeller and rudder of M.V. *Baltic Importer*.

example of this type I may mention the local icebreaker of this port, the *Göta Lejon*. *Oden* and similar icebreakers are built for breaking ice at sea and for convoying merchant ships of accepted strength and power to outside the destination port, where the local icebreaker takes over.

Many propeller damages caused by ice are dealt with here every spring, but I cannot recall having seen any ice damage caused to the propellers of the icebreaking tugs. These propellers are made of stainless steel and are of the controllable pitch type. Some of these tugs are in service every year when the opening of the Lake Wenern takes place and sometimes operate in remarkably thick ice. The extension of this icebreaking period is normally not very long, but I do think the very substantial construction of these propellers could make them useful also for icebreakers of intermediate size.

Mr. Crighton mentions the amusing fact that the icebreaker *Moskva* was built with the class notation "Strengthened for navigation in ice" I had the pleasant duty in the Gothenburg plans department to deal with a number of the detail plans for this ship in order to see if they fulfilled the Rule require-

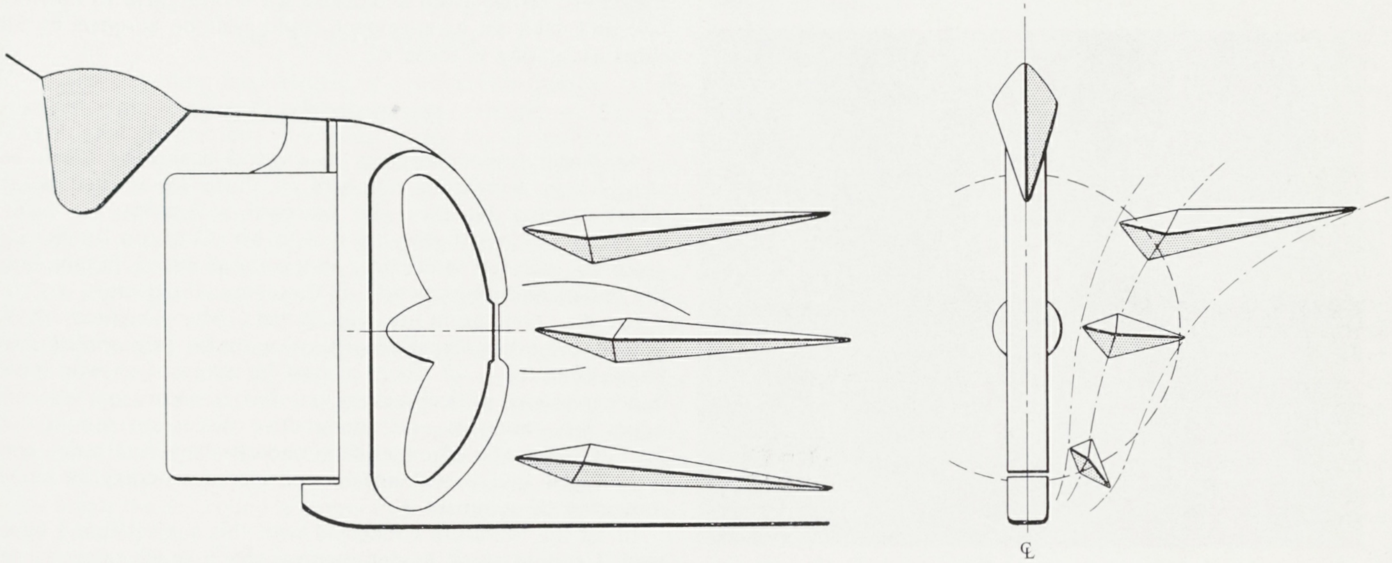


FIG. 5

MR. OVE NILSSON (Gothenburg)

Mr. Crighton has presented an interesting paper over an unusual subject. When reading this paper, it reminded me of a story told by the late professor in naval architecture here, Mr. G. Ambjörn, to his students. Prior to the World War I, Götaverken in hard competition with several European yards won a contract for an icebreaker to the Russians, and in February, 1912, the delivery of *Peter the Great* took part. Mr. Ambjörn stated that this incident was the real beginning of shipbuilding of any size in Sweden. The length of this icebreaker was about 170 ft.

Mr. Crighton divides the icebreakers in two groups, polar icebreakers and other icebreakers. Certainly none of the icebreakers mentioned by Mr. Crighton in Table I is intended for harbour use. They are all built for heavy duties. Between the *Oden* and the icebreaking tugs for harbour use I would suggest another group of icebreakers, the minor icebreakers owned by the harbours where they are stationed and where they serve the nearest area around the home port. As an

ments of this notation. They did. In this connection I would welcome Rules for icebreakers which will transfer the present descriptive note "Icebreaker" to a real class notation and which will also require more realistic scantlings as outlined by Mr. Crighton.

Particular care must be paid to the material in the hull plating and to the electrodes used, not only from the strength point of view but also from the fact that the hull is unprotected during the icebreaking period. Mr. Valanti, from Helsingfors, showed in a very interesting paper presented to the Scandinavian Shipping-Technical Conference (NSTM) 1960 in Oslo some pictures of the side shell of a Russian icebreaker after nearly two years' service in Arctic waters and in the Baltic. This icebreaker was stated welded with basic coated electrodes. From his paper the Photo No. 1 is quoted. Mr. Valanti further refers to results obtained when investigating the electro-potentials of various steel and deposited weld material from different types of electrodes. He states that killed steels are the most electro-negative ones and that ordinary ship steels (having low Si. content) are the most

electro-positive ones. For the deposited weld he gives the following results: the basic electrodes are most negative, the acid electrodes are most electro-positive and the rutile electrodes are somewhere between. The best result for use with the killed steels wanted here seems to be obtained by basic electrodes. So is the fact with the Finnish *Voima*, where the side shell is stated to have a Si. content of 0·4–0·5 per cent. This icebreaker had at the time of the report served seven years with no corrosion in the welds.

Leaving for a moment the icebreakers and transferring this interesting fact to a normal tanker or cargo ship having mainly A steel in the bottom and sides, the use of rutile electrodes should be a good choice from the corrosion point of view. The extremely high hydrogen content in this type of electrode, however, makes them in my opinion most undesirable in the shell of a ship, especially for the last runs not being normalised, and they are not to my knowledge used in Sweden for this purpose. What may happen with A steel and basic electrodes, however, after repeated renewal of corroded welds, as we must do here every year, is seen in Photo

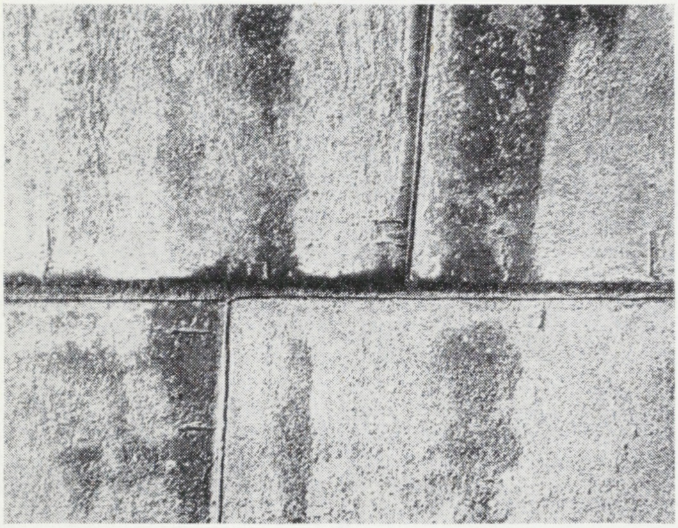


Photo No. 1

Photo No. 2

No. 2. Low hydrogen electrodes of new types with low corrosion speed when welded together with A steel are, however, now on the market and, in my opinion, the use of such electrodes should be made a class requirement for cargo vessels to have Ice Class notation.

Mr. R. M. HOBSON

The Author mentions that the icing up of sea suctions is a major problem and the real trouble here is that ice and slush is drawn onto the sea inlet grids and lodges there on account of the pump suction pressure.

The Society's Rules require two sea inlets, steam clearing, and warm water returns but the simplest way of freeing the accumulated ice is to change from one sea suction to another, thus allowing the ice at the grids to disperse.

With the advent of large diameter butterfly valves for marine use one such valve could be interposed between each sea inlet and the pump suction.

If the valves were mechanically linked it would be a simple matter to change from a blocked sea suction grid to the free one and such an arrangement could well be adopted by all ships navigating in loose ice.

Mr. J. WORMALD

As world trade continues to expand, icebreakers will be required in increasing numbers in those ice-affected areas where trading facilities and seasonal navigation are being extended and our thanks are due to Mr. Crighton for having given us such an interesting and comprehensive insight into the design and construction of these specialised craft.

In the conclusion to his paper, Mr. Crighton says, "Inevitably when experience plays a major role controversy reigns supreme . . ." There cannot be many of us who have had experience of icebreakers but this is no reason why his hopes for comment and constructive discussion should not be fulfilled; lack of experience underlies my first point and it is hoped that it will not be considered so crazy as to be unworthy of comment.

In all the literature connected with this subject that I have seen, I cannot recall having come across a single reference to the possibilities of using heat other than Mr. Crighton's to the use of heat from nuclear fission to operate a "bubbler" for melting river ice. Would it not be advantageous to augment the effectiveness of the heeling and trimming tanks by adding a certain amount of heat to whatever liquid is in them?

The benefits would appear to be two-fold; firstly, a reduction of the surface friction by producing a film of water between the hull and the ice and, secondly, the provision of that initial breathing space which engineers know can be relied upon to assist the breaking down of any supposedly perfect fixation. There must obviously be factors operating against the use of heat; are they economic, technical, or a combination of both?

Mr. Crighton suggests that steering gear be designed to put the rudder from hard over to hard over in 15 seconds when the ship is going ahead at full speed; unlike Mr. Lockhart in his paper on "Steering Gear", he makes no reference to a corresponding angle of helm and it seems to be asking too much from orthodox steering gear if the minimum angle to be covered in 15 seconds is 70° or thereabouts. Icebreakers are called upon to do a great deal of astern working and, for this

reason, the rudder assembly is bound to be vulnerable; is it not reasonable to assume that the risk of bending and/or twisting some part of the assembly will increase roughly in proportion to the angle to which the rudder is turned? If this is so and manœuvrability is of prime importance, where is the compromise likely to be made between manœuvrability and designed angle of helm?

Finally, it would be of interest to engineers to know more about the stern gear. Could Mr. Crighton say whether the conventional lignum vitae-lined sternbush and screwshaft with a continuous liner are standard fittings on icebreakers and, if so, whether special precautions are necessary with regard to the physical properties or the fitting of the bronze liners? Have oil glands ever been fitted in this type of ship and, if so, have they proved reliable in service? Have any operators of icebreakers, other than the Russians, had the courage to do away with propeller keys and keyways and to rely entirely on the interference fit of the propeller on the shaft? Has Mr. Crighton heard whether the Russian advances in this direction have been successful or not?

Mr. M. MOLANDER

As the Author has devoted a considerable portion of the paper to the design of icebreakers some remarks on that part additional to previous discussion might be of interest.

It is believed that the main reason for installing bow propellers in a modern icebreaker is to reduce friction between the ice and the bow of the ship thus enabling the ship if possible to proceed forward at a regular rate. This is a normal condition on the Baltic waters where, for example, a "Voima" class icebreaker may break its way through reasonably thick solid ice-cover at say six knots speed.

Two inward rotating propellers one at each side of the bow have proved to give the best flow and to wash the broken ice away from forward part of the ship thus reducing friction and resistance. Two bow propellers give also good steering possibilities which is, of course, of great importance, when the icebreaker operates in a narrow seaway or when she has to break the ice round a cargo ship, which has been stopped by pressing ice.

It seems inadvisable to install bow propellers in a Polar-type icebreaker due to the thick polar ice which may damage propellers and shafting.

To avoid the icebreaker being held in ice suitable lines, angle of entrance, angle of stem to base line and the angle of side hull to the vertical are adopted. Further, trimming and heeling tanks can be used for the same purpose. The maximum thrust of propellers can thus be designed for driving ahead, not astern for bow propellers as stated in the paper. The Polar-type of icebreaker does not have any bow propellers and still has to get clear of ice if it is stopped.

The bow has to be designed for the likely operating conditions in comparison with the displacement, beam and power of the icebreaker. The same applies to the after body which, however, might be more round shaped to protect the after propellers and also to leave a clearer way for following ships.

The form of the midship section is, of course, very important. The bilge radius in icebreakers built recently in Finland is smaller in comparison with the American ones. This gives a rather straightlined submerged form but still seems to be good if the angle of the ship's side to the vertical in way of the water line is kept big enough—about 20°. Due to the great beam and overall round form the icebreaker tends to have very rough rolling movements while driving in high open seas. The small bilge radius has proved to give better stability qualities by reducing rolling. Thus it is not necessary to have stabilisers or bilge keels both of which might easily get damaged.

Earlier it was usual to have big tumblehome to reduce deck area and thus weight. Nowadays the icebreakers built in Finland have reasonably small tumblehome to increase the effect of the side heeling tanks and to get more deck area, which is needed. I don't think that the icebreaker can operate so near other ships that a great tumblehome would help very much.

As stated in the paper the diesel-electric propulsion machinery seems to be still the most suitable. It is possible with D.C. type machinery to get great torque with small revolutions and to have reasonably constant effect over a large range of revolutions, which are claimed in the icebreaker. Diesel machinery has also small consumption thus enabling great acting radius. However, the diesel machinery in a very powerful icebreaker gets complicated specially from a maintenance point of view.

In between the power range of atom powered and diesel powered machinery one might think that gas-turbine-electric machinery, which could be installed in a smaller engine room and give less maintenance work, would find its place.

In an investigation made in Finland it was found that a total thermal efficiency of 37 per cent for full effect and of 28 per cent for 50 per cent effect could be achieved (*see* reference No. 1). This 50 per cent effect is quite usual for icebreaker operation. Hence the diesel electric machinery might still be the most effective.

As far as I know the usual damages in icebreakers are those in propellers and shafting not in the hull. These damages are, of course, very much dependent upon the manner in which the icebreaker is driven when meeting severe ice conditions. However, it proves that considerable attention should be paid to the design of shafting and propellers.

Finally, I would like to thank the Author very much for this interesting paper and to suggest two good papers not mentioned in the list of references, which might give someone further guidance on this very complicated subject.

Reference No. 1

C. Landtman: Tecknische Gesichtspunkte über Moderne Grosse Eisbrecher. Shiff und Heifen 1961. H.12 p. 1165–69.

Reference No. 2

Enqvist: Sjösättning av en stor isbrytare. (Launching of a great icebreaker—Read in N.S.T.M. 59 Meeting in Helsinki.)

Mr. A. G. BORTHWICK

I would like to congratulate Mr. Crighton on presenting his paper on an interesting if unusual subject. The construction of icebreakers in this country has been few and far between and the subject generally of their design and construction, confused. I am pleased that Lloyd's as a classification Society has given due consideration to the construction of these highly specialised ships. At least one classification Society has published strict regulations for their design and construction for some time.

I would like to add a few comments to the many interesting points Mr. Crighton has mentioned. On the question of block

coefficient certainly as stated it is difficult to vary this value very much from 0·50 when including a large bilge radius and ship side flare of 15° in the midship section. As Mr. Crighton points out the Canadian icebreakers have block coefficients up to as much as ·67 and certainly ·60 is generally quite common. This is basically because many of these ships serve a dual function as icebreakers and supply ships hence cargo deadweight is important. The method of obtaining this larger block coefficient is by reducing the flare angle of the midship plating contrary to the general practice of modern European icebreakers.

The exact function of the flare angle seems to be loosely defined by various authorities on icebreaking and J. G. Gordon in S.N.A.M.E. 1959 believes this large angle tends to worsen the icebreaking situation by tipping up large pieces of ice and passing them aft rather than breaking them up. The other view is that if the vessel is beset in an icefield it would be raised by the pressure of the ice rather than crushed. It is difficult to appreciate this happening and never seems to have been adequately reported. With the inclusion of heeling and trimming tanks in the modern icebreaker this situation should never really arise.

On the question of freeboard Det Norske Veritas states that it should be large enough for the ship to take up a heel of 20° before the deck edge is immersed. Two points the designer must bear in mind is that when the ship is charging smooth ice and riding up to where the step in the forefoot strikes the ice shelf, the freeboard aft should be large enough to prevent the deck aft from becoming immersed in association with the greatly reduced stability.

Foreign icebreakers, for instance Polish and Russian have much more stringent stability requirements to meet than under British Regulations. Suitable ranges of dynamical stability have to be satisfied which take into account wind pressures, hull form and icing-up ensuring the deck edge does not become immersed under these conditions which are likely to be met in service. These pressures are based on the particular service of the vessel and the lateral area above the waterline including allowances even for rails and rigging.

The rolling of these ships in a sea-way is usually bad as the Author comments and some form of stabilisation is required. In paragraph 5 page 15 the Author writes that bilge keels are usually torn off after their first commission. In the S.N.A.M.E. paper "Operational Aspects of Wind Class Icebreakers" by Rogers and Reece they state bilge keels have been fitted to the U.S. Wind Class and also to one or two other Canadian icebreakers, and have never been ripped off although sustaining minor damage to forward sections which require repair from time to time. The effectiveness of these bilge keels is reported to be not very pronounced and as Mr. Crighton states some form of passive or active flume stabilisation seems to be a more suitable answer. Passive types are being fitted on the latest Canadian icebreaker.

Mr. Crighton states that tank experiments involving icebreaking by model experiments do not seem to produce really worthwhile results. While this may be true to some extent, I think it would have been preferable if a critical assessment had been made of the sparse published work especially as he has emphasised the importance of hull form which is critical for this type of vessel.

The *Perkun*, a Polish icebreaker, and the only one to be built in this country for about 30 years, was tank tested for icebreaking qualities. I had the good fortune to work on the design of this vessel and had the opportunity to study cine films of the tests carried out by Saunders Roe. In short, the process was carried out by spraying wax over the surface of the water and later coating the wax film with a lubricant to obtain a surface with a coefficient of friction closely to that of steel on ice. Photographs of these icebreaking tests can be seen in a paper "Some Aspects of Icebreaking Design" by E. C. B. Corlett and G. R. Snaith read before the R.I.N.A. in March of this year. The results of these tests influenced the designing of the aft end lines and confirmed suitable fore end lines up to the waterline. Originally the aft end lines were similar to that of the fore body. It was noticed, however, when going astern that broken ice tended to be tipped up and be drawn down into the propellers. A decision was made to fill out the after lines to prevent this and in effect push the ice to the sides of the cleared channel. This is contrary to accepted practice and I would be pleased to hear the Author's comments. The fore end lines were given additional flare above the waterline to give added reserve of buoyancy and water shedding ability when pitching into a head sea. Although this vessel was for operation in seasonal ice conditions in the Baltic sea and not intended for Polar work it is worthy of note if only from the point of view of gaining experience in this particular field of design. This vessel was completed at the beginning of the severe winter of 1962/63 and was immediately engaged in icebreaking duties during that winter with considerable success.

In his paper "The Fluid Dynamics Laboratories of Saunders Roe" by W. A. Crago presented before the R.I.N.A. meeting in September, 1964, he states the tank has been used in the last few years to investigate the icebreaking characteristics of ships and to date seven designs have been tested of which *Perkun* was the first and would seem to indicate the icebreaking model testing technique has proved satisfactory. I would like to emphasise that these tests are for icebreaking qualities of the hull form and not to calculate the forces involved.

Mr. Crighton states that in some recent icebreakers it was the practice to use jets of water ejected at "supersonic speed" for the ship to clear crushed ice from the open channel. I cannot quite understand what is meant here and where the jets are situated. It has been reported high power monitors were fitted on the bow to remove loose snow ahead of the vessel so that it is always breaking smoother ice with low frictional resistance. Certainly the problem of lubrication has not yet been solved between the hull and snow-covered ice and undoubtedly is a major problem especially in the seasonal pack-ice conditions of regions like the Baltic Sea.

Mr. N. Flensburg

During a recent discussion with a friend in the Swedish Admiralty regarding icebreakers, mention was made of Mr. Crighton's paper and he was shown a copy. I have now received an official reply from his Department, and in view of the interest they have taken, I think it would be well worth while if their remarks could be included in the written discussion.

They say that they found the paper most interesting and based on comprehensive modern literature on the subject. It gives a good summary of the problems connected with the design of icebreakers and it should be of value when possibly devising rules.

Then they go on with the following comments:—

Aspects in the Design of Icebreakers

The dividing into types should appropriately be done according to the area of operation and certain special prominent details of construction in accordance with the following:—

(a) Polar icebreakers (Arctic and Antarctic) (no bow propeller).

(b) Sea icebreaker (temperature zones with moving sea ice) (two fore propellers).

(c) Harbour and inside of island icebreakers (areas with general compact ice) (with or without bow propeller).

The contribution of the bow propeller to the astern power is not so prominent. The principal object is washing of the bow (ahead), washing effect in pack ice (ahead and astern) and smashing and clearing of the ice.

The stem inclination of sea icebreakers in the Baltic varies between 23° and 25°.

L/B for sea icebreakers and harbour icebreakers as an average is 4·0. At lower values there is a tendency for deviation in course.

For *Oden,* for which particulars are given in Table 1, the speed, 16·7, is knots. The total power is slightly higher than stated, i.e. 10,650 s.h.p., which may be divided between the bow and stern propellers by 2 × 1775, 2 × 3550 s.h.p. respectively, revolutions (nominal) fore 180, aft 102, stem angle 23°.

Oil has not been tried in the rolling tanks for Swedish icebreakers. The rolling speed is of importance for the icebreaking capacity. In the latest Swedish ship *Tor,* and in the Finnish *Tarmo,* the time for a swinging period has been reduced to 45 seconds by arranging two pumps and four tanks. The amount of water should have a certain relation to the size of ship in order to obtain at least 6–7° rolling.

The displacement for icebreakers varies within large limits. In *Oden* the variable amount of water and fuel amounts to more than 25 per cent of the displacement.

Propulsion

The most essential characteristics of a diesel-electric icebreaker is, *inter alia,* the possibility for a quick power transmission from fore to aft and vice versa, and the improved torque, at low propeller revolutions and zero knots. For bow propellers, on the latest designs, four times the normal torque could be obtained.

Lately, the propellers have been designed for maximum efficiency at zero knots or very low speed. The efficiency in open water comes second. It is being considered to design the bow propellers for a maximum ice load corresponding to a lower revolution than zero knots revolution.

The bow propellers add considerably to the headway of the icebreaker in pack ice, on the contrary, not noticeable in open water. In ice one must, however, reckon that, as a rule, they are working with full effect. This is mostly the case in the direction "forward" (i.e. they force the ship ahead), but sometimes also in the opposite direction when washing.

These so-called "galloping" icebreakers, an example of which is shown on Fig. 3, can only be considered for harbour icebreakers.

Strength of Ice

Table II is incomplete. Ref. 2 (Jansson) gives further values, collected from a very extensive investigation in connection with full-scale experiments with the icebreaker *Mackinaw* (J. Osmondroyd, Investigation of Structural Stresses in Icebreaking Vessels, Research Institute, University of Michigan, Ann Arbor 1950).

Icebreaking Forces

The formulas under this heading give plausible values for Baltic icebreakers.

The importance of the rolling tanks in pack ice is very great.

Welding

No machining of welds has been adopted in the Swedish icebreakers for the reason of corrosion and strength. The advantage of a flush surface of the shell has not been investigated. Any drawback by having the welds unmachined has not been shown.

Other Aspects

Steam has not been used during recent years. On the contrary, some of the cooling water from the diesel engines has been led to the ice wells.

Table III

The following values relate to the *Oden* and *Tor*:—

	Oden	*Tor*
Year of build	1957	1964
L (VL normal)	80·85 m.	78·90 m.
B (max)	19·40 m.	21·20 m.
Draught (normal)	7·00 m.	6·50 m.
Keel plate	18–25 mm.	16–25 mm.
Bottom	16–24 mm.	16–30 mm. (E)
Sides	30 mm. (Coltuf)	30–34 mm. (E)
Sheerstrake	27 mm. (Coltuf)	13–27 mm. (E)
Main deck	9·5 mm.	8–9 mm.
Orlop deck	8–9 mm.	8–9 mm.
Forecastle deck	9 mm.	8 mm.

Personally, I would agree with the general remarks given by the Swedish Admiralty regarding the quality of this paper. I would also agree to their division of icebreakers into three types instead of two. With three types rules might be made for the "sea" icebreaker, and a scaling up or down made for the other two.

Tugs are used in Sweden as icebreakers in harbours and estuaries. These tugs are designed as icebreakers and their ice strengthening is heavier than required by the Society's Ice Class 1. There should be some minimum requirements on SHP, L and B, if such tugs are to be considered as icebreakers. They are to a large extent fitted with controllable pitch propellers. The ice path made by these small icebreakers is too narrow for the large ships which get damaged at their "shoulders" when proceeding in the path.

It is agreed that the "ice-breaking coefficient" s.h.p./displacement, which has been used in the past as a measure of the ice-breaking ability, is a poor parameter for assessing scantlings.

The scantlings of the side shell, main frames, web frames and side stringers in the ice belt should be based on permissible ice pressures. This was an Owner's requirement in the case of the *Moskva.* I would suggest that this method be adopted and figures for the permissible ice pressures given forward amidships and aft for the three types of icebreakers,

also permissible bending and sheer stresses. The size of the icebreaker should have influence and it seems correct to introduce a factor K, dependent upon SHP $\times$ L $\times$ B, as made by the Author in the Appendix.

The proposed method for assessing the scantlings of the bottom shell clear of the ice belt forward is not understood. L would be the suitable parameter here.

The service experience on the hull for "sea" and "polar" icebreakers, built after the war in Finland and Sweden, has generally been good, and only local weaknesses have been found. The corrosion of the underwater welds has been a problem, but is now overcome, when it is learnt that the electrodes should be related to the shell plating material. No damage has been found in way of superstructures.

AUTHOR'S REPLY

I would like to thank my colleagues who have taken part in the discussions for the valuable contributions and suggestions made on a subject about which very little firm or reliable data is known. Inevitably, the same point or question has been raised by more than one person and in such cases I have replied once only.

Clearly, experience working in all types of ice is the foundation upon which any recommendations put forward must be built.

There has always been and no doubt always will be, until conclusively proved, a division of opinion as to the value of simulated model tests in ice. This aspect of icebreaker design has been put forward by both Mr. Jensen and Mr. Borthwick and before replying to particular queries put forward by individuals I would like to say that in my opinion, from published data available, there does not as yet appear to be a material which satisfies, at one time, all the scale and similarity requirements for model icebreaking experiments.

Mr. Borthwick mentions a method of obtaining tank test results carried out by Saunders Roe for the Polish icebreaker *Perkun* in which wax was sprayed over the water and having a thin layer of lubricant superimposed, to obtain a surface with a coefficient of friction approaching that of steel on ice. I believe that this method, or one very like it, was first used in Russia, and the results although showing perhaps a rough pattern in icebreaker hull form, did not give sufficient data to enable the designers to forecast with any real confidence the likely behaviour of icebreakers operating under service conditions.

To Mr. Jensen

Icebreakers are compared by their icebreaking potential and this usually takes the form of horsepower divided by displacement. This ratio is therefore a designers ratio when comparing the likely size of icebreaker for the area of operation, etc. As icebreaker construction is almost always an evolution of experience from previous vessels, it follows that the ratio, horsepower divided by displacement, has been used either directly or indirectly from previous successful icebreakers. I have, therefore, given in the paper a basis for determining principal hull scantlings for polar icebreakers which should fit a large number of icebreakers in service to-day using this fraction. I do not, however, feel that this is the best method of determining the principal hull scantlings, hence the method outlined in the Appendix of the paper.

Fundamentally, an icebreaker is a powered tool breaking ice by virtue of its mass and velocity.

I have, therefore, suggested a method of determining hull scantlings by introducing a ratio of horsepower multiplied by displacement, or more easily SHP $\times$ L $\times$ B, which, although it does not give very close results for the main frames on all the icebreakers given in the Appendix, is nevertheless, to my mind, a more logical method for determining hull scantlings.

I have mentioned that the lines of the fore body should be repeated in the after body as a general requirement when designing the hull lines of an icebreaker. This is mentioned specifically so as to point out that the hull form aft of midships is expected to be able to do the work of the hull form forward of midships when the icebreaker is backing into the ice. There are, of course, other factors to consider, such as those given by Mr. Jensen and this means, in practice, that the after hull form is slightly different from the forward hull form.

The efficiency of the diagonal bracing system as fitted to U.S.C.G. *North Wind* is suspect. As Mr. Jensen has mentioned, experienced designers do not like the truss system as the strength depends upon (a) the strength of the strut brackets, and (b) the sudden collapse dangers inherent in a truss system subjected to very changeable and sudden forces. I have had unconfirmed reports that some of the American icebreakers have experienced trouble in the main hull structure and this may well be due to the truss system of framing adopted.

To Mr. Davies

It would appear that as Mr. Davies points out, the general grouping together of "Harbour and Estuary" icebreakers with "Non-Polar" icebreakers, as I have done in the paper, covers too great a range and his suggestion that there are really three classes of icebreakers is a good one. As I see it, to do this grouping it will be necessary to restrict the vessels to within certain geographical limits, with the polar icebreaker having no limit whatsoever.

To Mr. Gray

I do not intend to reply to Mr. Gray's contribution in detail, as I feel that it was not his intention that I should do so. I would like to thank him, however, for a really useful contribution which covers quite extensively the problems associated with the power plant design of an icebreaker. These problems are unique and call for special techniques away from the normal design problems associated with power plant design.

To Mr. Lockhart

With regard to the points raised on the horsepowers given in Table I, the *Ernest Lapointe* is a twin-screw icebreaker and does not have a single screw forward. For *William Carson* the total horsepower given in the Table covers for the ahead horsepower only and to be consistent should include the astern horsepower of 3330 s.h.p. However, as Mr. Lockhart has said the ahead horsepower only should be used for determining hull scantlings. With regard to the length of *Moskva*

the First Entry report and the Classing Certificate give the length B.P. as 382·5 ft.

Regarding the shell thicknesses put forward by Mr. Lockhart, based on s.h.p. divided by length, I am not clear how he makes an "adjustment for ice pressure" to obtain the thicknesses proposed. The SHP/L for *Moskva* is about three times greater than the SHP/L for *Perkun* whereas the shell thickness of *Moskva* is only just over twice the thickness of *Perkun*. As the type of ice usually met by *Moskva* is likely to be much more severe than for *Perkun*, it follows that the ice pressures exerted on *Moskva* will be far greater than for *Perkun*. It seems logical therefore to make a larger correction for ice pressures acting on *Moskva* than for *Perkun*, and this in turn should produce thicknesses for *Moskva* of well over three times that of *Perkun*.

I agree with Mr. Lockhart that a complete grillage system for the supporting structure should be applied when considering principal hull scantlings. One of the difficulties, however, is to determine the proportion of load taken by the shell and this can vary enormously with hull form. As I have emphasised in the paper, hull form is vitally important, far more so than for conventional vessels. Ice pressures can have quite appreciable differences over the vessel's length depending not only on the relative position of the ice to the hull but also depending upon form. If we are to draw up Rules for the construction of icebreakers based to some extent on theoretical considerations, some control should be made with regard to hull form. Obviously, whatever requirements are made should be couched in the broadest possible terms consistent with good hydrodynamic form and other design features which are the prerogative of the naval architect. However, I feel some control over hull form should be made as a new form could give resulting ice pressures well in excess of those assumed for determining principal hull scantlings.

The reason I have suggested a hard over to hard over time of 15 seconds for the steering gear, is not for the vessel navigating in open water. In icebreakers the rudder is often trapped in ice and the steering gear should be strong enough to enable the icebreaker to manœuvre clear. This means fitting a stronger steering gear than is normally fitted to conventional vessels and I have suggested that one way of obtaining this extra power is to halve the hard over to hard over time for conventional steering gears.

To Mr. Lindqvist

The reason I have said the broader the vessel the easier it can break ice, is perhaps an over simplification of the problem. Basically, power for power, a narrower vessel will cut deeper into the ice and force the ice apart, whereas a broader vessel will not go so deep into the ice field and "break" ice more efficiently. Obviously, there is an upper and lower limit and it has been suggested a low limit of $L/B=3{\cdot}5$ and an upper limit of $L/B=6{\cdot}0$ should not be exceeded.

Recent American designers have suggested that future icebreakers could have an L/B of up to 6·0 although to my knowledge no polar icebreakers have been built having these proportions.

To my knowlege Kort type nozzles have not been fitted to an icebreaker although much research has been done using models with triangular shaped propeller blades.

Mr. Lindqvist is quite right when he assumes that the rotating wheels fitted to the tug *Josef Langen* cause pitching and not rolling as mentioned in the paper.

I would like to thank Mr. Lindqvist for the very useful information he gives for ice pressures used by some Builders when designing shell and framing and also for his diagram showing the tensile strength of ice relative to salinity and temperature.

Mr. Lindqvist's suggestion of classing icebreakers based on specified loads is an interesting one but I cannot help feeling that if icebreakers were classed by the service restriction this would serve to give the same results but without introducing specified restrictive loadings of which really little is known.

To Mr. Tornqvist

As I have said in the paper, I would hesitate recommending the use of controllable pitch propellers for icebreakers and agree with Mr. Tornqvist in this respect.

I would like to thank Mr. Tornqvist for the remainder of his contribution and note his useful remarks regarding propellers, etc.

To Mr. Dobson

I have deliberately avoided drawing a border line between type 1 and 2 icebreakers. Without further research this is, in fact, a very difficult division to make, as, except for the very large and very small icebreaker, there is a fairly large group of icebreakers, all of about the same size, any of which might conceivably do a very good job of breaking polar ice and yet on paper appear not to be suitable.

Because of the very thick shell plating, I feel frame spacing does not have the same relationship to scantlings as conventional vessels. As Mr. Dobson has quite rightly deduced, the factor 0·54 in the formula $I/Y=K\times 0{\cdot}54\times l^2$ in the Appendix is derived by multiplying the frame spacing of 1·34 ft. by $0{\cdot}00402\times 10^{-2}$.

The ice pressures given in the third column of the Table in the Appendix are the actual pressures, knowing the actual section modulus of the frames, obtained from the formula $I/Y=0{\cdot}00402\ Pl^2\ s$ and not pressures quoted by the Builder.

It can be seen from the Table that the resulting ice pressures vary with each vessel and at one time I considered dividing the vessels into groups depending upon geographical limits of operation. I decided, however, to standardise the pressure and introduce a factor coupled to this pressure which would take into the momentum of the vessel—hence the introduction of $SHP\times L\times B\times 10^{-6}$. The K values are not, therefore, another way of writing ice pressure. Using the appropriate K value the section modulus can be quickly found and these values have been put back into the formula, i.e. $0{\cdot}00402\ Pl^2\ S$ and the P values found. These values are given in the last column of the Table and as pointed out in the Table *Abegweit* and *d'Iberville* although possessing satisfactory horsepower, displacement and other dimensional characteristics do not appear to have frame scantlings sufficient for polar icebreaking.

To Mr. Guthrie

For icebreakers of type 1, it is the cut up of the bow that cuts the ice and not the flat bottom. It has been suggested that ideally the waterlines should resemble the finer end of an egg and the introduction of a sharp section such as a bar keel will cause the ice to stick to it and build up a resistance. Any large vessel can become an icebreaker of sorts and in fact large tankers have been used to cut their way through thin ice. I agree with Mr. Guthrie in principle that if a shafting system is strong enough to be stopped in one revolution without damage, there does not seem to be any case for

preferring a four-bladed to a three-bladed propeller. However, some authorities consider that it is preferable not to invite excessive shocks to the shafting and four-bladed propellers reduce this possibility. Welding of the high quality steels usually associated with the construction of icebreakers is a problem and, in general, plating over $1\frac{1}{2}$ in. thick should be heated to 100° C. I think it doubtful that using the water in the heeling tanks as a heat sink for de-icing the sea inlets would be really practicable. The amount of water in these tanks is sometimes quite large and I think heat losses involved would be enormous at the very low temperatures of service. It could be quite an interesting exercise to determine the likely heat losses from the tank to the inlet to see whether Mr. Guthrie's suggestion is practicable.

I do not like the idea of a large open bay across the bottom of the ship for strength reasons, also I think it could be subject to continuous damage due to the ice beneath the keel. I cannot agree with Mr. Guthrie that the U.S.S.R. *Lenin* was an unsuitable choice of vessel to carry a nuclear reactor. The Russians are making great claims as to the prowess of the *Lenin* which is now more than five years old. According to "Fairplay Shipping Journal" 17th December, 1964, issue, the Soviet Information Service states that her performance in the Arctic has been faultless "and the technical expediency of building atomic icebreakers has been fully proved".

During the five years she has been in operation she has covered 75,000 miles, of which some 53,000 miles were through ice and her nuclear plant has been stable and easy to handle. The atomic shielding is stated to have been extremely reliable and there has not been a single case of radiation affecting any member of the ship's crew. It should not be forgotten that two more atomic icebreakers are to be built for the U.S.S.R.

It is common practice to fit ice knives and fins to conventional cargo ships which already incorporate some ice strengthening. It would not seem advisable to do this and thereby permit the vessel to operate in ice when no other strengthening is fitted, however.

To Mr. Nilsson

I would like to thank Mr. Nilsson for his very helpful contribution, particularly with regard to the operation of icebreakers under service conditions. As has been mentioned elsewhere in the paper and in the discussion, the quality of steel and the type of electrode to be used are very important and Mr. Nilsson has raised some very interesting instances of corroded seams and butts in icebreakers. I think his suggestion that the choice of electrode should be made a class requirement is a valid one.

To Mr. Hobson

With regard to Mr. Hobson's comments on the introduction of large diameter butterfly valves interposed between each sea inlet and the pump section, I take it that this valve is intended to be a quicker and simpler means of changing over the suction lines from one inlet to the other. I understand it is mainly ice slush that blocks up the filters and as the pump suction continues, turns this slush into a solid ice block, making the clearance of the inlet very difficult. Although I am not an engineer, the introduction of butterfly valves such as proposed by Mr. Hobson seems to have some merit. However, if I may refer to Mr. V. T. Bülow's contribution to the discussion to Mr. Clayton's paper "Pumping and Piping Arrangements" regarding the reply to the question raised by Mr. J. Guthrie in that paper, it would appear that steam blowing is considered to be one of the best methods for clearing ice slush from suction lines.

To Mr. Wormald

The introduction of a heat source to melt ice would present an admirable solution to the problems of dispersing ice. Unfortunately, however, the amount of heat necessary would, I think, make this an impracticable proposition. Heeling tanks in icebreakers are relatively large, besides which the heat required to pass through shell plating some 2 in. thick of sufficient quantity to melt the surrounding ice, however partially, may be such as to raise quite serious problems regarding temperature stresses. It must not be forgotten that the tank structure itself will not be anything like 2 in. thick and the heat radiation through the tank bulkheads would probably mean insulating the external structure of the tank. With regard to the questions raised on stern gear, here I have consulted my engineer colleagues and have been informed that the lignum vitæ-lined sternbush and continuously lined screwshaft usually fitted to conventional vessels are also generally fitted to icebreakers, but the adoption of oil glands is not usually encouraged due to shock factors normally experienced by icebreakers. Apparently, as Mr. Wormald has stated, propeller keyways have not been fitted on the latest Russian icebreakers but as these have not been in service very long I'm afraid I cannot say whether the Russians have been successful in this venture or not.

Unfortunately, I cannot say whether special precautions are necessary regarding the physical properties or fitting of the bronze liners.

To Mr. Molander

As Mr. Molander suggests, an intermediate step between atomic and diesel powered machinery could well be the gas-turbine-electric power plant. However, as he himself has stated the poor thermal efficiency is a drawback to this type of installation. Perhaps with further developments, the thermal efficiency of the gas-turbine-electric plant may be improved, but of course, high capital costs might rule out this possibility. I am not too happy, however, about the introduction of turbines in icebreakers due to sudden shock loads on the reduction gearing, but I am confident that our engineering colleagues will come up with the answer to this problem.

To Mr. Borthwick

Mr. Borthwick's contribution is a welcome one as few naval architects, at least in this country, have the opportunity to work on the design of icebreakers and his comments on hull flare, stability requirements and tank testing, etc., are particularly interesting. I do not propose to make comment again on the controversial question of tank testing although I sympathise with designers who must produce a hull form capable of carrying out the duties peculiar to icebreakers. Mr. Borthwick makes reference to my statement that recent icebreakers make use of water jets ejected at supersonic speed to clear crushed ice from the open channel. These are not small low powered jets quite commonly used to produce a film of water between the ice and the vessel's hull, but high powered jets which are advocated quite enthusiastically by some authorities to fulfil several objectives such as (1) manœuvring the vessel whilst beset by ice, (2) to help keep the ship's head in position should a sudden gale arise, (3) to clear rough

ice ahead, (4) and of course to keep the coefficient of friction down between the ice and the hull.

To Mr. Flensburg

I would like to thank Mr. Flensburg for his comments and suggestions. Regarding the proposed method for assessing the bottom shell clear of the ice belt forward, this has been suggested as being a function of the length of the vessel to a corresponding "basic" breadth and frame spacing, corrected for actual breadth and frame spacing.

I would also like to thank Mr. Flensburg for passing on the paper to the Swedish Admiralty. Their comments are of particular value as they come from a body whose function is to design, build and operate icebreakers and the Society is very grateful for their views. Most of the points raised have been dealt with elsewhere in the discussion, but I was very interested in the rolling range and periods given by the icebreakers *Tor* and *Tarmo* and agree that the amount of liquid used in the rolling tanks should bear a certain relationship to the displacement of the vessel.

Printed by Lloyd's Register of Shipping
at Garrett House, Manor Royal,
Crawley, Sussex, England

FOR PRIVATE CIRCULATION AMONGST THE STAFF ONLY

Lloyd's Register Staff Association

Session 1964-65

Paper No. 4

CORROSION CONTROL

by

O. M. CLEMMETSEN

LLOYD'S REGISTER OF SHIPPING

71, Fenchurch Street, LONDON, E.C.3

The Author of this paper retains the right of subsequent publication, subject to the sanction of the Committee of Lloyd's Register of Shipping. Any opinions expressed and statements made in this paper and in the subsequent discussion are those of the individuals.

CORROSION CONTROL

by O. M. CLEMMETSEN

INTRODUCTION

Over the years there have been five papers on corrosion and corrosion prevention presented to the Staff Association, and as the earliest of these was in the third session, 1922/23, it is evident that the problem of corrosion and the desire to mitigate its effects has never been far from the mind of the Society. Indeed, so far as the Ship Surveyors are concerned, most of their periodical survey work on existing ships arises from the effects of corrosion and if it was eliminated then the frequency of hull Special Surveys might well be reduced.

This paper is concerned with tankers since the increase in the proportion of the world tonnage devoted to this type of ship, in whose cargo tanks the problem of corrosion is seen in its most acute form, has led to a corresponding increase in the time and effort devoted to control it. Although corrosion has not been eliminated, striking improvements have been made in the past decade, and it can fairly be claimed that it is now under more control than ever before.

Although it may be a rather limited field, there is no doubt experience obtained in protecting cargo tanks will lead to advances in other directions, as owners become more conscious of the advances which have been made and therefore more willing to try out new ideas.

The information given in this paper has largely been obtained from the brochures of manufacturers and designers of corrosion control systems, and the vast amount of material in the technical press, etc. It will, therefore, not be complete without the comments of Outport Surveyors who will be able to state from personal experience just how successful these methods are proving in practice and whether they are making subsequent survey work easier.

Pattern of Corrosion in Cargo Oil Tanks

The mechanism of corrosion has been fully described in a previous L.R.S.A. paper by J. M. Murray in 1952/53 and it is sufficient here to state that the type of corrosion with which we are usually concerned in shipbuilding is that due to differences in electro-potential within the steel itself. If steel is completely free from millscale then the multiplicity of anodic and cathodic areas will lead to uniform rusting and a comparatively slow rate of diminution in sea water since the presence of a continuous rust film slows down the reactions.

In the case of white oil tankers carrying light petroleum spirits, the corrosion procedure appears to be that rust builds up to a certain thickness after which blisters start to form due to lack of adhesion between the rust and the underlying steel and also the fact that the rust scale is greater in volume than the steel from which it has been derived. These blisters eventually burst and on vertical surfaces fall off, resulting in an area of bare steel (anodic) surrounded by rust (cathodic). Accelerated corrosion occurs on the bare patches but in the meantime the surrounding rust itself breaks off. The process is accelerated by the fact that the petroleum spirits help to remove the rust and the net result is overall accelerated diminution in thickness. Corrosion rates of 15/1000 in. per year have been reported in this trade. Rather surprisingly it has been suggested that for these ships the rate of corrosion is similar whether tanks are ballasted or not which may be due partly to the fact that many white oils contain dissolved oxygen; or to the effect of washing and humidity. In both types of tank, however, the maximum corrosion occurs on the deck head and upper parts of the tank where build-up and shedding of rust is more rapid, accelerated possibly by vibration of these parts.

In the case of black oil tankers carrying boiler fuels and heavy crudes, the surface of the tank becomes coated with an oil film or waxy deposit which partially protects the surface. Corrosion in such ships has less overall effect on the strength, due possibly to the fact that the oily deposit hinders underlying rust from breaking off, but where corrosion does occur it is at an accelerated rate, and results in pitting. Gaps in the oil film which retain water are more likely on horizontal surfaces and so these are the areas where pitting normally occurs. Such pools remain when the tanks are empty and corrosion can continue during the loaded voyage since the pools are trapped by the cargo. Certain crudes, notably from the Middle East, have a fairly high sulphur content and it is possible that this also contributes to the pitting corrosion by formation of H_2SO_4. Rates of pitting up to 3/16 in. per year have occurred. It should be noted that there are other crudes which are mainly aromatic and corrosion patterns for these will be similar to those in white oil ships.

Until recently, the presence of millscale, which is cathodic to steel, could lead to increased corrosion, in both black and white oil trades, in those areas free from millscale, but with the fitting of shot blasting equipment in most large shipyards it would appear that this form of corrosion will be of diminishing importance in the future.

Slag left on welded seams has a similar electro-chemical effect to millscale and should always be removed. Hand welding, particularly overhead, may corrode quicker than machine welding due to its rougher finish which makes adequate paint coverage more difficult. It has also been found that low hydrogen, i.e. basic coated electrodes, may give rise to more corrosion than welds made with rutile coated electrodes due to the greater volume of $FeO–Fe_3O_4$ inclusions in the former.

Corrosion of steel cannot take place without a supply of oxygen and therefore the purpose of coatings is to prevent access of water or air to the steel surfaces. Replacing air by an inert gas in empty tanks or in spaces above ballast or cargo has a similar inhibiting effect on corrosion. The alternative approach is to prevent the electro-chemical action between adjacent anodic and cathodic areas of steel by the principle of cathodic protection as described later.

Control of Corrosion by Defined Ballasting only

Since the amount of corrosion depends to a certain degree, at least in crude oil carriers, on whether tanks are ballasted, it is worth while considering whether any reductions in total corrosion can be obtained by restricting the ballasting to certain tanks.

In some large tankers now built, there are tanks which are solely used for water ballast and these are sometimes sufficient for fine weather ballasting so that the necessity of using other tanks for ballast is restricted to heavy weather conditions. In addition, these permanent ballast tanks permit cargo to be

loaded and tanks to be de-ballasted simultaneously, which is economically advantageous.

Opinion seems to be equally divided as to whether centre or wing tanks should be used for ballast. There is certainly more structure in the wing tanks and it would appear that the renewals would be reduced if only the centre tanks were ballasted, on the other hand the reduction in stability, due to free surface, will be greater if centre tanks are ballasted since these are generally twice as wide as wing tanks, and if wing tanks are empty the chances of corrosion, due to condensation, will be increased when these tanks are exposed to the sun in the tropics where the humidity is greater.

One might also add here that the temperature and therefore rate of evaporation and degree of humidity in cargo tanks may be reduced by coating the upper surfaces of the decks with a reflecting paint. However, one has then to contend with glare and resulting discomfort to the crew. Green has been found to be a good compromise between the two conflicting requirements but a special grey paint has also been developed which is as effective as green. In case the latter seems an obvious choice it should be mentioned that a conventionally formulated grey will be no better than black so far as reflecting capabilities are concerned.

The washing procedure is also a factor in corrosion but unfortunately this is a necessity in crude carriers since if the corrosion scale, sand and sludge is allowed to remain and accumulate in the tanks it will interfere with drainage. Washing is usually done at sea during the ballast voyage and either cold or hot sea water may be used. The latter is more efficient and would be necessary if the following cargo is to be white oil, but it tends to increase corrosion by removing the oil film in crude tankers and also any calcareous film in cathodically protected tanks, thus necessitating repolarisation of the steel in the latter case. The use of hot water may also increase condensation and has been found to increase the gas concentration level. Experience shows, however, that cold water washing gives adequate cleaning even in crude carriers and that hot water need only be used about once a year. Fresh water has been suggested for washing tanks and while this would no doubt reduce corrosion the cost rules it out.

The latest practice regarding tank cleaning is to accumulate all tank washings into one tank and allow the water to settle out, after which as much uncontaminated sea water as possible is pumped out from below the oil. If the next cargo is a similar one it is loaded on to the consolidated washings, and if it is not similar the washings are discharged at the loading port. While it is not known whether this will affect the corrosion pattern, it will reduce oil polution. It is interesting to note that this scheme, which has been adopted by the major tanker companies in joint consultation, was suggested in a paper to the N.E.C. Inst. in 1958 by Lamb of Shell Tankers.

History of Tank Coatings

The United States Navy began evaluating methods of controlling corrosion in 1952. Coatings were favoured rather than cathodic protection since it was essential that the jet fuel carried in Navy tankers should be free from the impurities which would be present when the fuel was carried in dirty tanks. A coating called Saran was developed based on a vinylidene chloride-acrylonitrite compolymer which fulfilled the purpose but suffered from the disadvantage that it had a low flash point of 30° F. which made its application somewhat hazardous. The disadvantage of the low flash point of the original Saran has now been overcome with the added advantage of ability to cure down to 40–50° F.

Twenty-one Navy tankers had all their tanks coated with the original Saran in 1954 but other commercial coatings were being developed concurrently, principally inorganic zinc silicate coatings with some epoxies and these now equal Saran in performance. After some trial tanks had been coated with zinc silicate, seven complete tanks were coated by one large tanker operator in 1956. These experiments were followed by the U.S.N.S. Yukon trials from 1957 to 1961 when 17 coatings of various types and makes were applied to the cargo tanks by three different shipyards. A complete record was kept of the cargoes carried and from the results an inorganic zinc silicate and an epoxy were found to be best.

On this side of the Atlantic the emphasis seems to have been on epoxy resin rather than zinc based paints due possibly to less carriage of refined spirits here and experimental coatings of tanks began about 1955 in tankers carrying both crude and refined spirits with encouraging results.

In all the foregoing cases the coatings were applied to existing ships, whose plate surfaces had to be thoroughly cleaned for the purpose. Even so, these surfaces were not as suitable as would be the case in new construction and it was difficult to remove traces of oil cargo. It was evident, however, from the small amount of breakdown which did occur that even better results would be obtained by applying the coating to new construction.

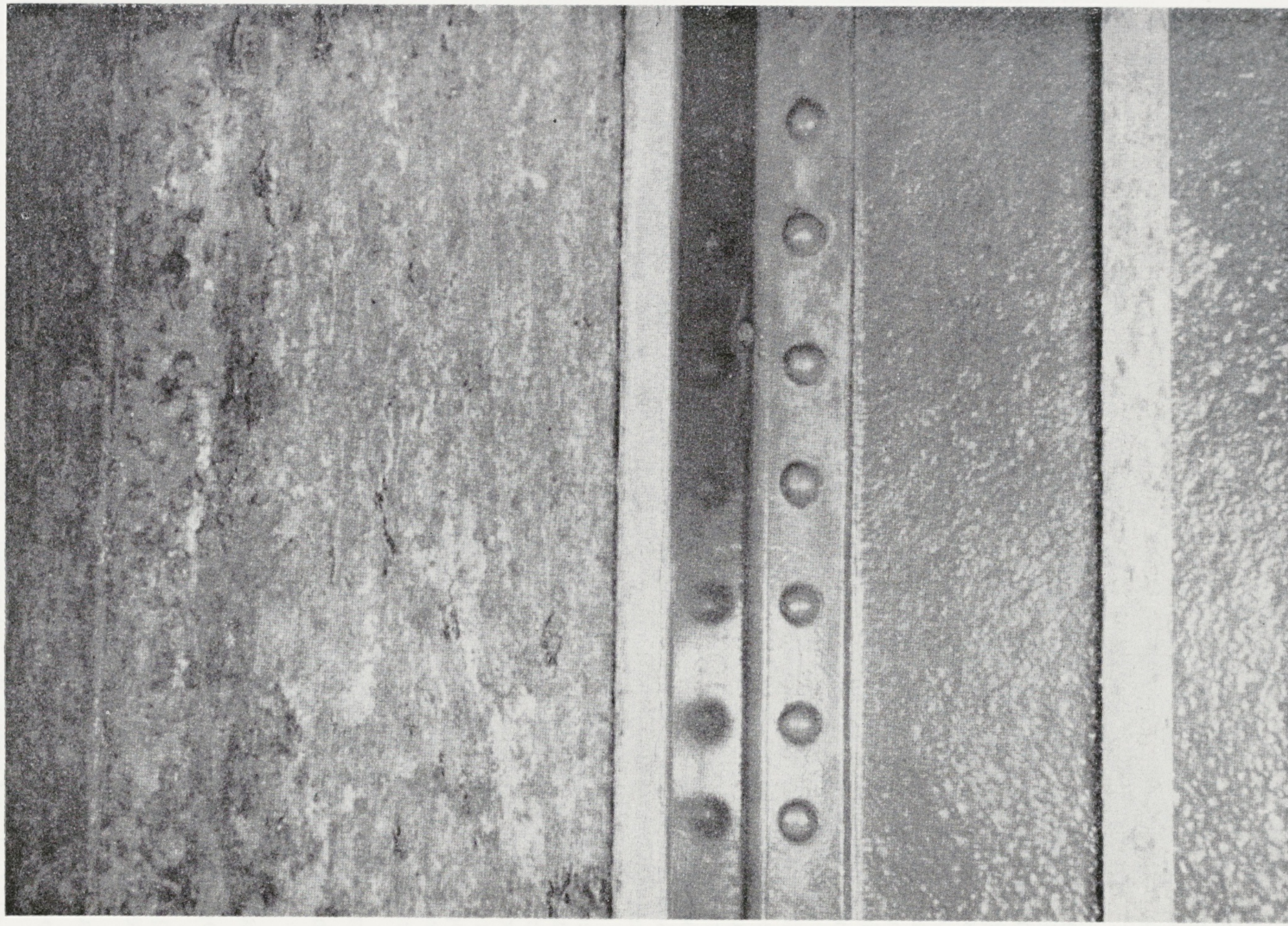
Apart from the fact that coatings lead to reduced maintenance costs they help to eliminate contamination of mixed cargoes due to leaking of corroded bulkheads, and make any cleaning much easier and more thorough apart from considerably reducing this operation in white oil ships. White oil products are delivered much cleaner and increased cargo flexibility is obtained due to improved ability to transport successive different cargoes with less cleaning. As there are no pockets of gas behind rust scale, gas freeing becomes easier. Reductions in scantlings, giving an increased deadweight, are now a further advantage.

Changes in Rules

By the end of 1961, it had become evident that the above types of coatings were in fact capable of withstanding the rigours of tanker operation and that those owners who wished to take advantage of these methods had a definite case for a reduction in scantlings. In this connection, it might be mentioned that the 1959 Tanker Rules embodied minimum thickness requirements, which were not in the previous Rules, for the purpose of combating the increased corrosion which was then being experienced. These minima principally affected the upper parts of bulkheads and the web plates of girders, stringers, etc.

An amendment to the Rules was therefore passed by the Technical Committee on 25th January, 1962, which permitted a 10 per cent reduction in the scantlings of bulkhead plating, stiffeners and certain internal girders and webs, provided an approved system of corrosion control was fitted.

At that time the approved systems consisted of one of the types of coating referred to above or cathodic protection, the latter having also been demonstrated to be an effective means of reducing corrosion in appropriate conditions. These two methods or a combination of them, remain the main systems although other proposals have been made, such as dehumidification and inerting of cargo tanks, and the use of oil or water soluble inhibitors. It should be noted that of all the



By courtesy of British Paints Ltd.

PLATE I

Coated and uncoated areas after 20 months' service in refined oil tanker. Test area prepared by shot blasting.

systems proposed only the coatings offer the chance of complete protection to the parts coated and the other systems only reduce corrosion rates.

The scantling concession gave a considerable fillip to corrosion control systems since the high cost of coatings could be partly offset by the saving of steel weight and initial cost, e.g. in a 775 ft. B.P. 100,000 tons tanker having a tank length of 560 ft. with six cargo tanks, the saving in weight is estimated to be 600 tons of which 140 tons would be accounted for in the deck and bottom and associated longitudinals.

Since an owner may prefer to retain the full Rule scantlings even with a corrosion control system and thus defer wear and tear renewals to a later date, owner's permission was a condition of the Society's approval for the scantling reductions.

Recent amendments to the Rules passed by the Technical Committee on 16th April and 21st May, 1964, have extended the area over which scantling reductions may be approved, to include a 5 per cent reduction in thickness of the main longitudinal strength items subject to coatings being used for corrosion control in the tops of tanks.

Since coatings must be applied to dry surfaces, the Rules regarding tank testing have also been amended to permit testing after coating provided the structure is complete in all respects before coating and any riveted seams are hose tested (from outside the tank if necessary).

In white oil carriers all the items for which reduced scantlings are desired must be coated, and conversely, if there are some items which it is not desired to reduce, then these need not be coated. However, it will be noted that the revised paragraph D.4020 of Notice No. 2 of the 1964 Rules states that "Special consideration will be given to the extent of protection required in tankers intended solely for the carriage of crude oil".

In such ships where coatings are employed, then, subject to the owners' consent, the full reductions may be obtained on all items, but the actual surfaces to be coated may be restricted to those where either atmospheric corrosion or pitting corrosion is most likely to occur, i.e. horizontal surfaces and structure at tops of tanks. The remaining surfaces are considered to be protected by the wax film from the crude oil. The actual extent of the coating may be as follows:

Tanks used for Ballast only

All surfaces for which reductions are required are to be coated.

Cargo/Ballast Tanks which are always full

All surfaces in the top 5 ft. (1500 mm.) plus the upper surface of all horizontal items in the remainder of the tank. Bottom shell, bottom longitudinals and girders, the last named to be coated to the level of the top of the longitudinals.

Cargo/Ballast Tanks which may be slack

All surfaces in the top half of the tank plus the upper surface of all horizontal items in the remainder of the tank. Bottom shell, bottom longitudinals and girders, the last named to be coated to the level of the top of the longitudinals.

Cargo only Tanks which are always full when loaded

All surfaces in the top 5 ft. Bottom shell, bottom longitudinals and girders, the last named to be coated to the level of the top of the longitudinals.

Cargo only Tanks which may be slack when loaded

All surfaces in top half of tank. Bottom shell, bottom longitudinals and girders, the last named to be coated to the level of the top of the longitudinals.

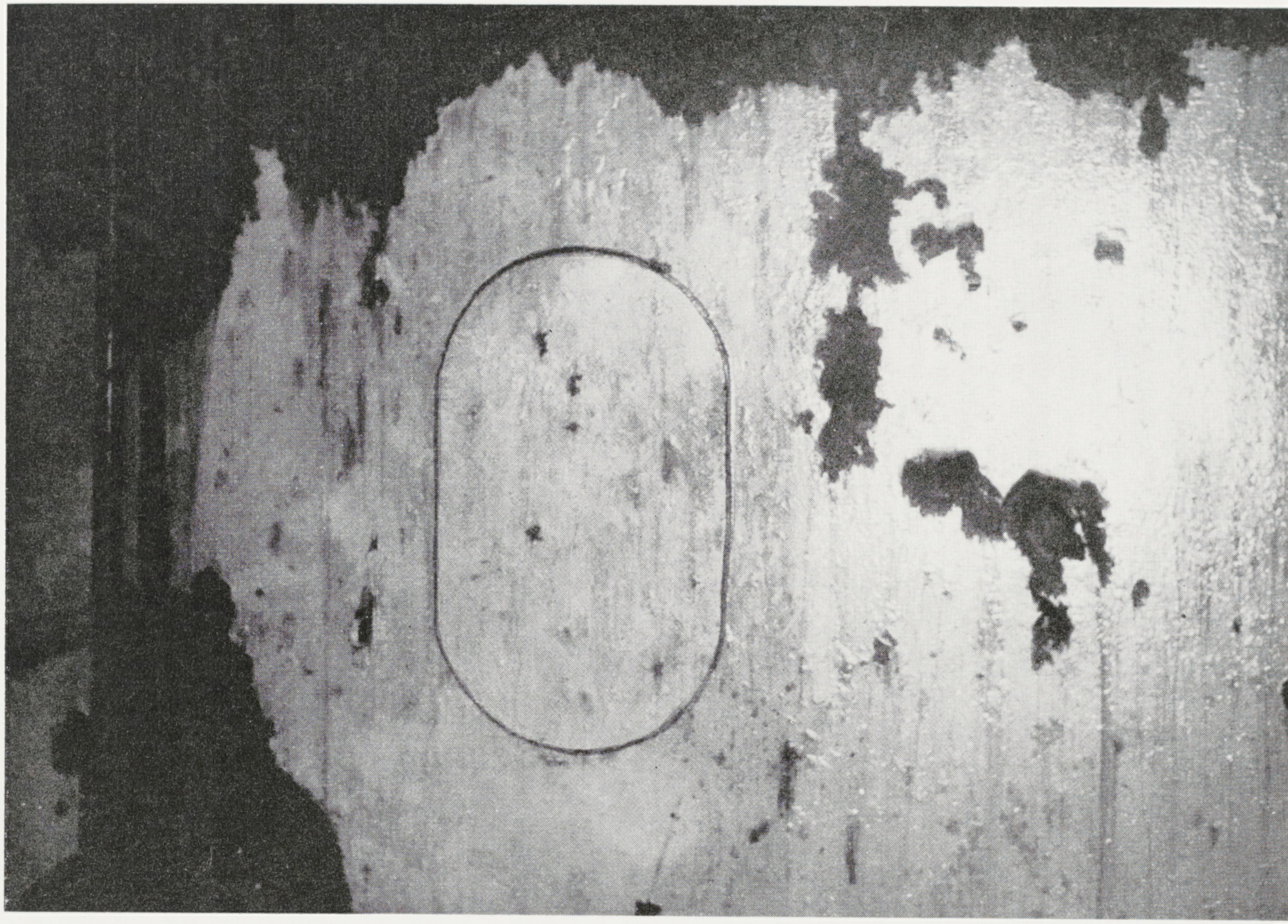
Tankers having the above scheme of painting will have the class notation "C.C.—Crude Oil—Defined Ballasting". The loaded and ballast conditions in the trim and stability book must of course be consistent with the scheme of the painting, and the various conditions examined for longitudinal strength in the usual way.

Reductions in bottom shell and/or deck and associated longitudinals and girders can only be obtained if these items are protected throughout the length of the cargo tanks. However, there will be no objection to reducing scantlings of top and/or bottom longitudinal material in either all wing or all centre tanks, provided strakes of shell or deck, which are common to protected and unprotected tanks, are not reduced.

If it is not desired to reduce the bottom shell and/or deck with their associated longitudinals and girders, then these items may be left uncoated. However, the side shell and the internal structure, excluding the sheer strake and bilge, may be reduced independently of the deck and bottom, provided the extent of the protection of these items accords with the purpose of the tank as given above.

Corrosion Allowances

In any discussion of scantling reductions as a result of improvements in the corrosion characteristics, the question naturally arises as to what corrosion allowances are present on ships' structures. The Rules mention specific increases derived from experience to take account of excessive corrosion in certain places, e.g. limber and bottom strakes of bulkheads in cargo ships, and by implication, tops of bulkheads in tankers, etc., but elsewhere the extent to which deterioration may be allowed will depend on the location and importance of the member, e.g. longitudinal strength is of more importance than the strength of internal bulkheads. Apart from the above, ship classification Rules are now much more scientifically based than in the past, due to increased knowledge of the stresses which are likely to be experienced, and this has led in many cases to overall reductions in longitudinal scantlings, especially in the top-sides of tankers. From this aspect, therefore, a tanker built some years ago could well have an appreciably greater margin of longitudinal strength *in a given loading condition* than the same ship would have if built to-day. Regarding the words in italics in the previous sentence, the Rules specify a minimum standard of longitudinal strength, but if the lay-out of cargo spaces and pattern of loading is such, that the still water stress is always well below the maximum permitted by the minimum modulus, then such a ship could, in theory, be permitted a greater reduction in scantlings than one where the stresses would frequently be at the maximum values. The latter type of tanker could be one with a short cargo tank length combined with a large C_b or in the case of a cargo ship, one where the minimum scantlings have had to be increased due to empty deep tanks amidships, or long cargo forecastle, combined with small C_b's. In addition, in the case of tankers the weardown due to corrosion in deck longitudinals which are exposed on two sides to cargo tank conditons will obviously be greater than that of the plating to which they are attached. (This may not apply to bottom



By courtesy of British Paints Ltd.

PLATE II

Test area (which originally terminated a little below the top of the photo) after 64 months' service in crude oil tanker showing majority of breakdown at edges. The surfaces were originally cleaned by mechanical chipping followed by wire brushing, degreasing and wiping which left a somewhat imperfect surface.

longitudinals in crude oil carriers.) The permissible reduction in deck plating will therefore depend on the proportion of the total top side area which is in the deck and longitudinals.

It will be seen from the foregoing that a fixed corrosion margin based on thickness cannot be applied as far as longitudinal strength is concerned since the vital factor is the allowable reduction in section modulus. As it seems probable that a reduction in modulus of 10 per cent could be allowed on present Rule scantlings before renewals are required, the reductions now permitted in tankers will allow a margin for deterioration should the corrosion control system fail, or be allowed to fall into disuse when the ship has reached a certain age.

As regards internal members, it has been common practice in the past to allow a 25–30 per cent reduction in thickness of web plates, bulkhead plating, etc., before renewals are required and with the 10 per cent reduction in scantlings of such members now allowed, it follows that a reduction of only 22 per cent will be permitted on internal scantlings which have been approved with reduced thicknesses.

It must therefore be borne in mind by owners that it is their responsibility to maintain the corrosion control system, and failure to do so will lead to earlier renewals than would otherwise be necessary.

Surveyors on new construction are reminded that approved midship sections must show both the full Rule scantlings and the reduced scantlings. Without such a plan to guide them, Surveyors will be placed in a very difficult position at future surveys.

Usually, corrosion control reductions are similar in each tank throughout the cargo tank length and this is essential as regards deck and shell, but there have been cases in the past where, due to the material ordering position at the time of the change in the Rules, reductions have only been possible in the internal members in certain tanks. In these cases, it is essential that full information regarding the areas where reductions have been made, accompanies the First Entry Report.

COATINGS

List of Acceptable Coatings

As stated previously, the scantling reductions permitted by the Rules gave encouragement to corrosion control systems, and as a result, a steady flow of applications has been received from manufacturers of coatings who are anxious to learn whether their products can be used for this purpose.

In general, all inorganic zinc silicate or epoxy resin based coatings formulated for cargo/ballast tank service are acceptable for this purpose, but it was decided that the Society must have information on the coatings to be applied, and accordingly each manufacturer who approached the Society was asked to provide information on his product, such as type of paint, applicability, number of coats and thickness, together with any other relevant information. They were also asked to state the actual service experience which had been obtained in tankers, together with any experimental evidence which would demonstrate the efficiency of the coating. Summaries of this information are circulated to the Surveyors in Plan Letters. To date, 39 paint manufacturers have submitted information and the systems considered consist of 33 epoxies (of which ten are high build types), 16 coal tar epoxies, and 13 zinc silicates.

As will be gathered from the section relating to history of coatings, certain manufacturers have had a long experience with these systems and they are obviously in a better position to demonstrate the efficiency of their products than those who entered the field at a later stage. It would be impracticable and unfair to restrict the acceptable brands of coatings to the manufacturers of long standing, since this might have the effect of retarding progress, and such action has not been taken. This is perhaps not a serious drawback as although there may be differences between the formulations of different brands of coating their main constituents are similar. Evidence to date indicates that major differences in service performance, are more likely to arise from insufficient surface preparation and incorrect application, than from differences in composition, and these difficulties are only overcome by experience. It is for this reason that the Society reserves the right to draw the attention of owners and builders to cases of limited experience in any instance where such a product is proposed for a particular ship. It cannot be too strongly emphasised that the choice of a particular brand of coating remains the responsibility of the owners and/or builders, and they will, no doubt, be influenced by economic as well as technical considerations in these matters. They should, however, not minimise the difficulties which are likely to be encountered in shipyard application, especially if this has to be done in winter, and they should not accept paints unless the manufacturer has given full details of the methods of mixing, pot life, application methods and surface preparation.

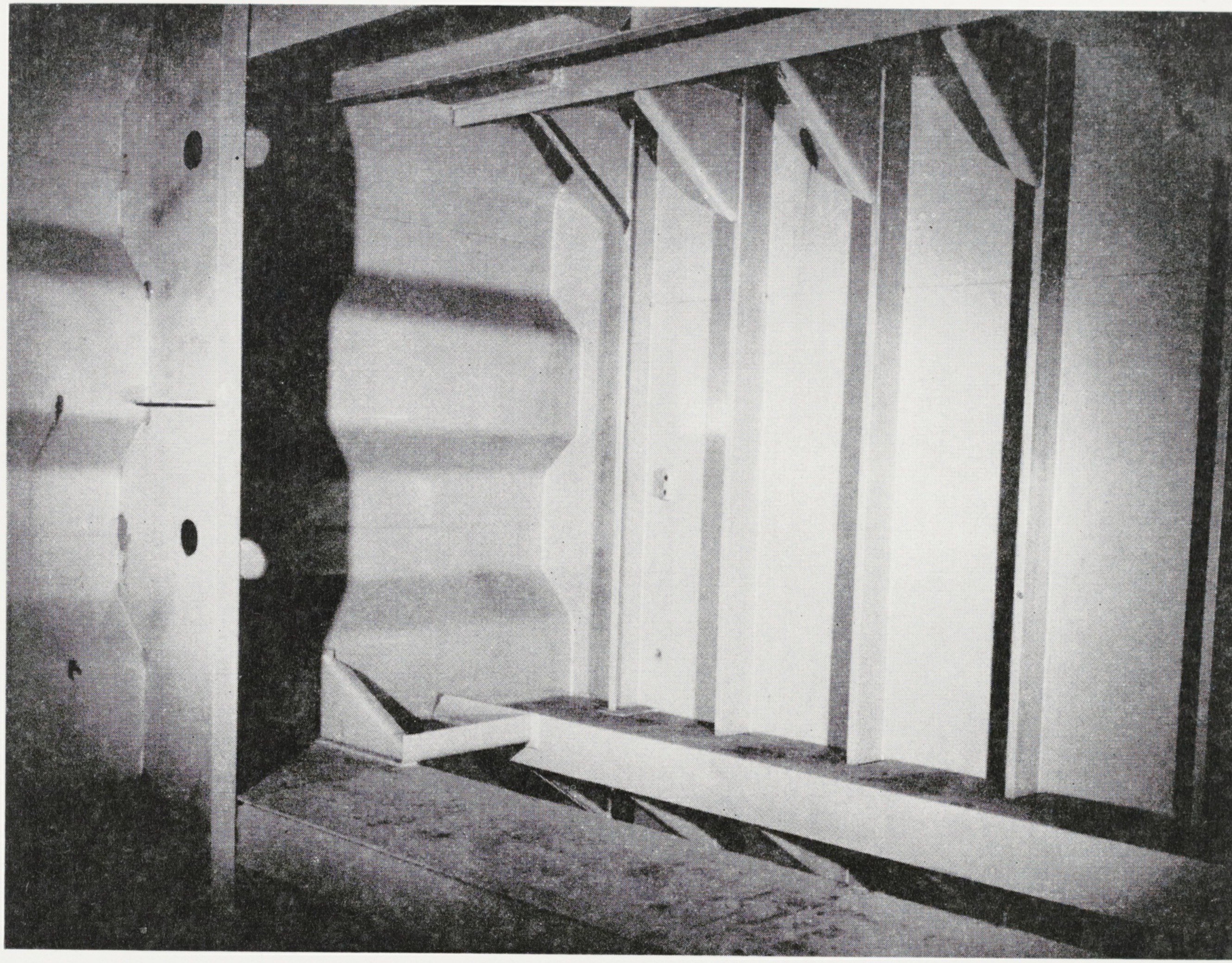
Testing of Coatings

The only satisfactory test of a coating is its behaviour in actual service, but experiments have been devised which attempt to simulate service conditions. Most effort in this direction seems to be concentrated in the U.S.A. where the aim of the United States Navy is to find a coating with a 10-year service life. For this purpose a test programme has been instituted which consists of putting coated panels through the following test cycle:—

1. The coated panels are immersed either in a synthetic or natural sea water solution at a temperature of about 80° F. for one week.
2. Following salt water immersion, the panels are totally immersed in a 40 per cent aromatic synthetic gasoline of a standard formulation at a temperature of about 80° F. for one week.
3. The panels are totally immersed for two hours in hot sea water at 175° F. to simulate conditions encountered when tank cleaning.
4. Each panel is placed in a closed container and sprayed at a pressure of 25 p.s.i. with hot synthetic sea water from a standard jet at a temperature of 175° F. from a distance of $2\frac{1}{2}$ ft. for 10 seconds.

The above cycle of tests is repeated 20 times. The panels are wiped with fresh water and dried for 48 hours. The upper third of each panel is then recoated to $\frac{1}{2}$ in. from the edge, with one coat of the finishing coat. It is allowed one week to dry and the test cycle is then repeated five times and the panels are inspected for failure.

From past experience, it is considered that passing the above cycle 26 times should ensure prevention of corrosion for at least 18 months, but may extend to four years. Recent practice is to repeat the cycle until a predetermined rate of failure has been reached, rather than subject a panel to a fixed



By courtesy of British Paints Ltd.

PLATE III

Almost intact surfaces in tanker carrying mostly white oils alternating with ballast after 20 months' service. Steelwork pickled but unprotected during erection. Surface wire-brushed before painting.

number of cycles. It is considered that if 3 per cent failure occurs after one year or a 15 per cent failure after two years then the system has failed. At the Annual Tanker Conference in 1962 it was considered that for a 10-year performance all manufacturers' thicknesses should be increased as follows:—

Epoxies 8–15 mils, Coal Tar Epoxies 20 mils and Zinc Silicates 2–4 mils.

The thickness of the epoxies is considerably more than is usually provided, but then, so far as is known, it has not been the commercial operator's aim to provide a 10-year trouble-free life.

Hand instruments have been developed to measure paint thicknesses. In one example a magnetic spring loaded "pencil" is used in which the "lead" of the pencil is attracted to the steel beneath the coating, when the case is gradually withdrawn from the surface. The point where the "lead" leaves the surface under the action of a tension spring can be noted on a scale of thickness. Other more sophisticated instruments give direct readings using electro-magnetic principles. Paint thicknesses are frequently given in microns and it should be noted that 25 microns is approximately 1 mil. ($\frac{1}{1000}$ in.)

Paint Formulation

Paints usually consist of a pigment in a binder to which there are normally added driers and solvents. The amount and composition of the drier will depend on the conditions of temperature and humidity under which the paint may be expected to dry, and the amount of solvent will depend on the required viscosity which will in turn, depend on whether the product is to be brushed or sprayed and if the latter on whether or not an airless spray is to be used. No driers are, however, used in cold cured epoxy paints as these cure by a chemical reaction between the epoxy resin and the amine or polyamide used as curing agents.

In the epoxy paints the epoxide resins are the binders and titanium dioxide may be used as the pigment in light coloured finishing coats. In inorganic zinc silicates zinc is the inhibitive pigment.

Epoxy Resin Coatings

Epoxy resins are a condensation product of epichlorhydrin and diphenylol propane and are used in the manufacture of various groups of coatings which may be broadly classified by whether or not they are single pack paints and whether or not they require heat to harden them. In cargo tanks we are only concerned with two pack materials in the epoxy amine or epoxy/polyamide groups which cure at ambient temperatures the amine or polyamide being the curing agents. These coatings have good adhesion and flexibility with good resistance to acids, alkalis, solvents and oils. Epoxy/amines appear to have better solvent resistance than the epoxy/polyamides. Sea water resistance of both types is less than their resistance to the other liquids mentioned and their resistance to fresh water is less than that to sea water. Exposure to fresh water can cause paint softening and eventual blistering, but provided the coating is not exposed for more than a few days it will recover its properties. Tank testing with fresh water is not therefore likely to present difficulties and, in addition, contaminated river water has less effect than potable water. Amine cured epoxies are more susceptible to fresh water softening than polyamide cured epoxies, but as the former have better acid and alkali resistance they are usually chosen for vegetable oil deep tanks. In the above circumstances the paint manufacturers should be consulted when prolonged exposure to fresh water is contemplated, e.g. when shipping fresh water in a new tanker.

Careful attention is necessary in mixing all these paints and also with regard to the pot life. Equipment must be thoroughly cleaned when there is likely to be a prolonged pause in the work.

The above coatings can be used in both black and white oil carriers, but for black oil carriers, epoxies extended by coal tars are becoming more popular. The latter are extremely tough and flexible and have excellent water resistance but less solvent resistance. The latter quality is, however, not very important where only heavy crudes are to be carried but, as these coatings are near black in colour, the advantage of a light surface is lost. (They may, however, be overcoated with light coloured normal epoxies.) Cold cured epoxy resin paints are generally applied in four coats to give a minimum dry film thickness of at least 5 mils. Adjacent coats may have different colours to ensure that proper coverage is attained.

Coal tar epoxies can be applied in one coat of 8 mils and, because of this greater thickness, they are less sensitive to "less than perfect" surface preparation.

As normal epoxies contain a high percentage of solvents (up to 50 per cent) several coats are necessary to obtain the desired thickness, and yet avoid sagging. However, "high solids" or so-called solventless systems have been developed in the last three or four years, and these can be applied in thick films of 8 to 10 mils, and are less affected by humidity and low temperature during application. As paint failure can be caused by solvents which have been entrapped between coats applied in too quick succession these paints reduce the chance of this happening. In addition they are more likely to be impervious to moisture. The pot life of high build coatings is much less than that of the normal types.

It must be pointed out that the risk of misapplication in the form of thinner areas or pin holes is less with multi-coat systems, and for this reason two thinner coats of say 5 mils of high build coating are preferable. Alternatively, a thin viscous primer with a thicker top coat might be desirable.

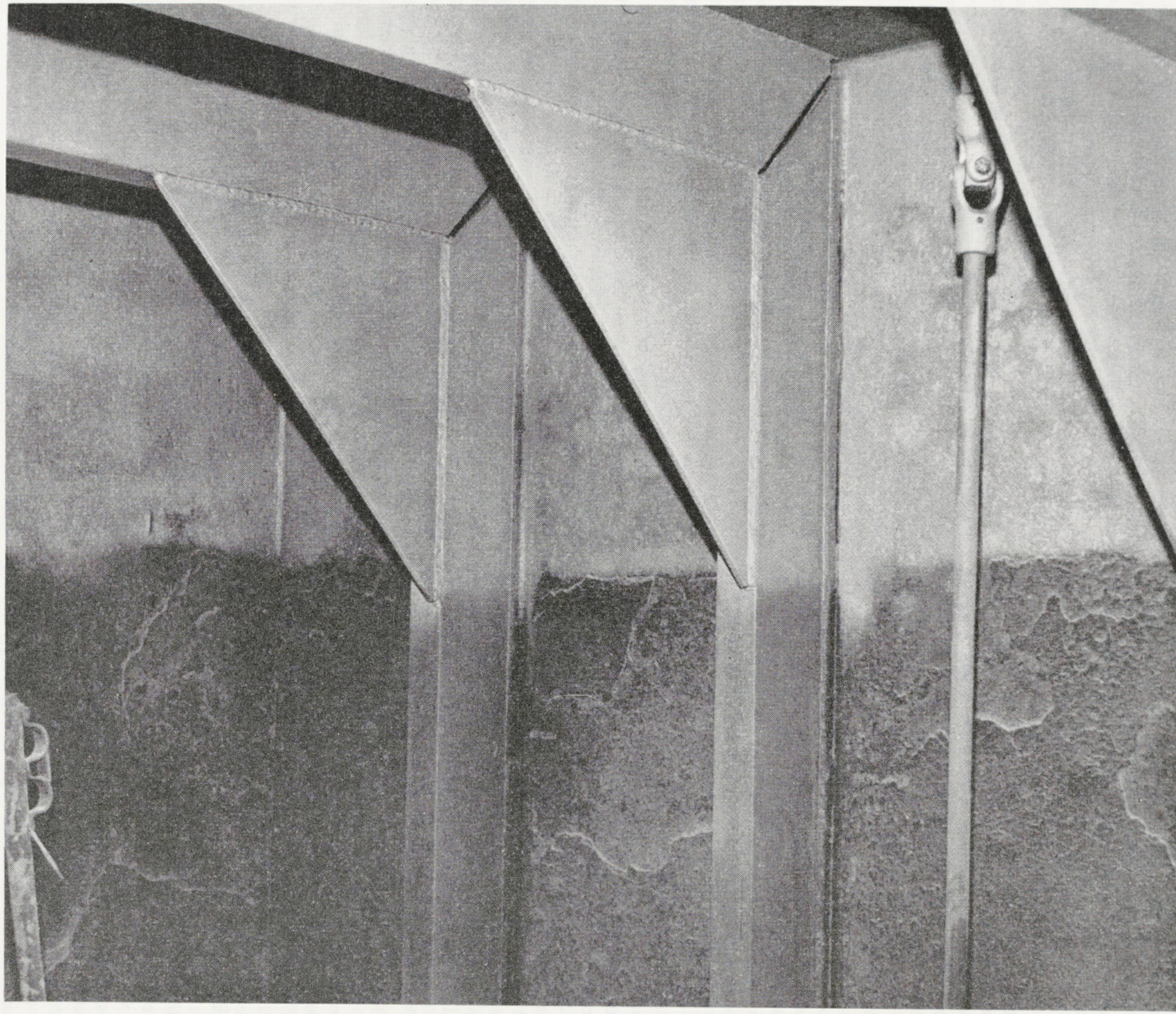
The normal and coal tar epoxies cure slowly at temperatures below 10° C. (50° F.) and require about 24 hours to cure between successive coats at temperatures above 10° C. The final coat should be left to cure for a week before any cargo or ballast is loaded. This should be borne in mind for tank testing.

Mention might also be made of the epoxy phenolic resins which combine excellent resistance to solvents, acids and alkalies, and salt water but have the disadvantage of requiring a high temperature (about 165° C.) cure. The use of such a coating will depend on whether its properties are essential to the service and this may well be the case in chemical carriers.

Vinyl resins may exhibit very good acid, alkali and water resistance but poor solvent resistance. They have the disadvantage also of having a low flash point.

Inorganic Zinc Silicate Paints

This type of paint, which originated in Australia before the war but was developed in America, is basically a finely divided zinc powder in a sodium silicate binder. The two components are supplied separately and mixed immediately before use as in the case of the epoxies and the resulting coating when cured is insoluble. The earlier types require a separate curing coat about two hours after the first coat and this curing coat dries in about two hours and curing is completed



By courtesy of British Paints Ltd.

PLATE IV

Deckhead of nine-year-old tanker showing difference between rusty and blast-cleaned surfaces prior to painting.

in 24 hours. The curing solution is acidic and inflammable and adequate ventilation in confined spaces is therefore essential, but the humidity must be kept low to ensure a cure.

These coatings are normally applied at 2½–3 mils thick, and will not cure completely if applied in thicker coats. The surface preparation is therefore more critical than with the thicker epoxies, shot blasting to white metal being required with an anchor pattern not exceeding 1 mil. This means that the coating must either be applied immediately the plate or section leaves the blasting machine or the fabricated units must be blasted and coated immediately. The former procedure would present difficulties in the case of immediate spraying, as it may not be desired to coat both sides of the plate with the same type of coating, for instance in the case of a shell plate. The third alternative is to blast the completed structure which is a very costly operation. The first two methods will in any case involve the subsequent blasting of welding or cut edges, e.g. man holes which have been made after coating, also those parts which have been locally damaged during the fabrication process. Welding may take place on these coatings without deleterious effects.

Types of coating have now been developed in which the coating and curing solutions are mixed at the spray nozzle, and in these coatings a relatively high humidity of between 50–85 per cent with a temperature not less than 20° C. is necessary for curing. The self curing types may be applied in thicker coats of 3–5 mils. Although expensive to apply, all these coatings have the advantage that they are single coat systems.

Zinc silicate coatings are highly abrasive resistant and are particularly good in solvents, which is probably the reason for their popularity in the U.S.A. where such trades are generally more important than in Europe. While the high metallic zinc content renders them less resistant to strong acids or alkalies, this factor means that they will protect by galvanic action any scratches or local abrasion. While suitable for intermittent ballasting in accordance with normal practice, they are not suitable for continuous immersion in sea or fresh water unless overcoated with vinyls or epoxies.

Importance of Satisfactory Surface Preparation

In the descriptions of the coatings given previously, emphasis has been laid on the need for a good surface preparation. This includes not only the complete removal of millscale but the preparation of a suitable surface to which the paint may readily key. The term "anchor pattern" is used to describe the profile of the plate when ready for the primer. When paint is applied, it will tend to form a coating with a flat surface, and if the surface of the steel is not completely smooth it will obviously be thicker in the "valleys" than on the "peaks". If, as is generally the case, the paint contains solvents, the evaporation of these produces shrinkage and this shrinkage will be greater in the valleys where the coating is thicker, thus, reproducing on a smaller vertical scale, the profile of the steel, although whether this happens in the case of a thin rapid drying shop primer applied after shot blasting is a matter for conjecture. As the degree of protection depends on the film thickness at the thinnest parts, it is necessary to restrict the heights of the peaks in order to avoid an unnecessarily thick coating, but on the other hand, completely smooth surfaces will not provide a key. Where thick coatings are applied, such as the coal tar or high build epoxies, it is obvious that the height of the peaks is of lesser importance than when the coatings are thinner, but as most plates are primed immediately after blasting with a shop primer which has a thickness of about ½–1 mil, the life of the primer, and therefore the state of the plating for applying the remaining coats at a later date, will still depend on the initial plate profile.

Methods of Surface Preparation

Power brushing will not be capable of producing a satisfactory plate surface which will ensure long life for the high performance coatings being considered in this paper, although they may be satisfactory when concentrated on a very small area depending on the degree of rusting present. As a measure of their "ineffectiveness", it has been estimated that on a plate left in an industrial atmosphere for 12 months, wire brushing will still leave behind between ½–1 lb. of rust per square yard in the pores of the plate, and this is four times the weight of a normal coat of paint.

The use of pickling for removing millscale has hardly had a place in commercial shipbuilding, although it has been used extensively in naval construction in the past when shot blasting facilities were not available. Although millscale is effectively removed, the resulting surface is very smooth with little anchor pattern. The surface is dark and mat and any defects in the plate are less easily observed than is the case with blasted plates. If used in association with epoxy paints, the concentration of acid used in phosphatising should not exceed 0·5 per cent, otherwise adhesion of the paint may be impaired. It does not compare with more modern methods for economy and speed of production with large plates and sections.

Flame cleaning consists of using a bar or similar oxy-acetlylene burner to heat the scale and pop it off by differential expansion. It is more effective on plating which has been weathered since, with new tightly adhering millscale, the heat may be conducted through both millscale and steel which would not produce the differential expansion required. For full effectiveness, it should be followed by wire brushing and the removal of loose debris, with a primer applied while the steel is still warm. This procedure may present difficulties in practice, but is necessary as tests on flame cleaned surfaces to which the primer had been applied when the plating had cooled, indicated that the adhesion of the primer was considerably reduced. In these circumstances, flame cleaning is not commonly used in new construction, although it has obvious advantages in removing old surface coatings where shot blasting would be less effective due to clogging of the shot.

Blast cleaning is now the generally accepted means of surface preparation. For initial blasting of plates and sections, the machine used will probably be of the Wheelabrator type, where the shot or grit is fed on to revolving paddles which throw it by centrifugal force at the surface to be cleaned while the plate or section is fed through at a predetermined rate. The spent abrasive is collected and sieved and the unbroken abrasive is returned for further use. From practical experience it appears that the best results are obtained when the machine has been in use for some time, and consequently the abrasive consists of a mixture of both old and new material.

The size of anchor pattern depends on a suitable combination of air pressure or Wheelabrator speed and the type and particle size of grit or shot, the smaller the mesh through which the abrasive can pass, the shallower the anchor pattern will be, while increasing the specific gravity of abrasive of

uniform size will cause greater surface roughening and better removal of scale. Sharp abrasive may also be expected to penetrate the plate to a greater extent producing a deeper anchor pattern, but as mentioned previously this is not always desirable, hence, a better pattern is usually obtained with a mixture of old and new grit. The anchor pattern should ideally be about 2 mils for epoxies and less for zinc silicates, but this is not always achieved in practice where isolated peaks of 4 mils may occur. After some time in service, discoloration may take place in way of these peaks and if the coating is locally removed over the area of discoloration a small rust speck will be found at the centre. This should be cleaned out and recoated, and further trouble in this area is unlikely as the peak has rusted back to the level of the surrounding anchor pattern.

For blasting *in situ* as is required for local preparation in damaged areas, small portable machines are used in which the abrasive is propelled through nozzles by compressed air, and these machines may either employ a closed system (Vacublast) which collects the abrasive, filters it and re-uses it, or they may use an open system where cheaper shot, e.g. steel or copper slag, is used only once. Care should be taken when using machines which have not a "dead man's handle" type of valve, since a machine which is laid down while working could seriously damage the plate. In experiments by the Admiralty, it has been found that a ·35 in. plate could be penetrated in 3½ minutes using angular steel grit with the nozzle 3 in. away from the plate.

Mechanical blasting owes its popularity to the fact that the treated surface forms an ideal key for subsequent coating, free from scale, dust and chemical deposits, and with the advantage that it can be a completely automatic operation. As a by-product, it shows up surface defects in plates which otherwise might only become visible when the plates are being worked.

A very exhaustive investigation into the preparation of ship plates has been carried out by Wilson and Zonsveld (N.E. Coast Institution 1961–1962). For impeller type machines, best results, i.e. maximum amplitudes of not more than 3 mils, were found to be attainable with cast round steel shot and cut wire, but the authors did not consider it advisable to recommend a standard grade of shot or grit, since the choice of an abrasive may depend on the degree of atmospheric rust present as opposed to millscale. Sand blasting is not used in the U.K. as this is forbidden for health reasons in enclosed spaces. It also has the disadvantage that it may leave occlusions which impair the effectiveness of primers.

Standards of Surface Preparation

The U.K. has so far not developed any standards for the qualitative assessment of surface preparation, and one must turn to the U.S.A. for assistance in this matter, where the Steel Structures Painting Council have prepared a guide covering cleaning by solvents, hand and power tools, flame cleaning (new steel), blast cleaning and pickling. The two standards most often referred to in connection with the high performance coatings dealt with in this paper are SSPC–SP 5–63 White Metal Blast Cleaning, and SSPC–SP 6–63 Commercial Blast Cleaning, but an intermediate standard, SSPC–SP 10–63T Near White Blast Cleaning, has recently been introduced. Photographic guides to the appearance of the various surfaces have been produced with the exception of 10–63T, and both the standards and the photographs have been jointly agreed with the Swedish Standards Association.

White metal blast cleaning is required to produce a uniform greyish slightly roughened surface completely free from millscale and all foreign matter, such as oil or grease, corrosion products and oxides. Commercial blast cleaning permits slight shadows or streaks caused by rust stain and slight residues of rust in pits to the extent that two-thirds of each square inch of surface shall be completely free from impurities. White metal blast cleaning has been recommended for zinc silicates and commercial blast cleaning for epoxies. Coating of the blasted surface should take place preferably within 24 hours of blasting, but in any case before any visible or detrimental rusting occurs. In North Europe where the relative humidity regularly exceeds 60 per cent (in the U.K. it exceeds 70 per cent for nine months of the year) these conditions entail immediate coating as a bloom can form on the steel in three hours. A simple method by which one could ascertain whether there is any rust in the minute pits in the plating consists of rolling out a short length of wide Elastoplast on to the plating and then removing it. If there is any rust it will adhere. This test is particularly useful in view of the short time between blasting and priming with modern automatic plant.

Paint Application

The method of paint application may have considerable effects on the efficiency of the coating, and the various methods are considered below.

The use of a brush has the advantage that paint can be worked into the surface in different directions, and this is especially important on a rusty surface. The use of brushes with extended handles leads to less uniform coatings as there is less control of the brush.

Although the use of rollers considerably speeds up the painting operation, their efficiency does not compare with the brush since the roller rests on the humps and will not reach the hollows. There is also a tendency with rollers to brush the coating out too thin. Again, the use of extended handles reduces the efficiency of the application, with the further disadvantage that they do not permit cross rolling.

The foregoing methods are only mentioned in passing, as the coatings dealt with in this paper are almost universally applied by spray. In a conventional spray, the paint is projected through a nozzle either by gravity, by pressure on the pot, or by suction caused by air flow (suction cup). The paint is atomized by jets of air around the nozzle and this action can cause bounce back, especially in corners, if the nozzle is held too close to the work, or can cause overspray on adjacent surfaces. The use of airless spray is now increasing, and in this process the spray is not mixed with air but is propelled by hydraulic pressure. Very high pressures are necessary to atomize the paint due to its viscosity and pressures of over 2,000 p.s.i. and nozzles of about 0·011 in. and 0·024 in. diameter, are required for ordinary and high build coatings respectively. Much greater penetration and adhesion are claimed for this process, and much thicker coatings can be applied in one pass. Due to the small nozzle the paint must be finely filtered and the equipment maintained in first class condition. As with all spray methods, there is no chance of removing surface contamination as is the case with brushing.

When considering the question of paint application, one should not omit the consideration of the question of designing for good painting. As all paints are applied in liquid form, they possess a surface tension which has the effect of dragging the paint back from the edges which are thereby thinly coated. This effect can be overcome by removing all sharp

edges. Naturally, this is a difficult and expensive matter but it is worth bearing in mind that bulb plates for instance will be more suitable for painting than angles, and corrugated bulkheads better than stiffened bulkheads, also that the omission of scallops will help in this matter. In any case, particular attention should be paid to the painting at the edges of face flats and lightening holes and it will probably be found that in existing ships these are the points where deterioration of the paint first occurs. Continuous welding can be protected more easily than intermittent welding.

Shop Primers

Assuming a satisfactory surface preparation the most difficult coat to apply is the first and, of course, all other coats depend on it. It would be preferable if the shop primer and subsequent coats were all supplied by the same manufacturer, but this not usually possible since automatic priming after shot blasting is now general practice and this coat must be suitable for a variety of subsequent coatings used for inside and outside work. It is probably for this reason that it has so far not been practicable to blast and prime paints at the steelworks since it would not be economical to coat different plates with different shop primers, as this would require hand spraying. For reasons outlined earlier it is also not possible to blast the plates only at the steelworks, and leave the priming until the plates arrive in the shipyard. In practice, there is co-operation between the paint manufacturers regarding the suitability of shop primers with various top coats, so the matter is not so serious as would first appear.

The requirements for the ideal shop primer have often been stated, and are as follows:—

(a) The primer to adhere and remain intact until the finishing coats are applied, i.e. up to 12 months in some cases and yet to be less than 1½ mils thick.

(b) The primer to be touch dry in under five minutes permitting almost immediate handling under ordinary atmospheric conditions.

(c) The primer not to interfere with welding or cutting and not to cause noxious fumes with either process.

(d) The primer to resist the working of the plate during normal fabrication processes and also to resist abrasion from personnel walking on it.

(e) The primer not to interfere with adhesion of subsequent coatings which may be different on both sides of the plate.

Some of these requirements are conflicting, since, although a thin coat will dry quickly and have less effect on subsequent welding, it will not give lasting protection.

As all plates must be thoroughly cleaned by brush or air before subsequent coats are applied (even if damaged areas are not present), and this may entail degreasing and washing with fresh water, it has been suggested that it may be better not to shop prime if extensive shot blasting is necessary after fabrication, but only to wire brush immediately before painting. Such a procedure is not recommended in the atmospheric conditions prevailing in North Europe where quite a hard scale can form in a few months which will be impossible to remove by wire brushing. As already stated complete shot blasting *in situ* is very expensive.

Apart from the necessity for preserving rust-free surfaces for subsequent overcoating, it has been claimed that the use of shop primers has led to increased productivity because the absence of rust has given improved working conditions. Slag and weld spatter are more easily removed from primed than unprimed surfaces.

As the strong solvents used in many epoxy resin paints will dissolve normal shop primers, the practical choice of the latter is limited to those mentioned below.

Zinc and aluminium are the two main pigmenting materials used in shop primers. They may be combined with various binders such as vinyls, polystyrenes, cold cured epoxy resins, epoxy esters, chlorinated rubber, etc. The percentage of zinc varies from 60–80 per cent. Since zinc is a harder material than aluminium, it may be expected to resist abrasion and mechanical damage better than the latter.

The foregoing types of primers protect by covering the surface with a non-porous film, and additional coats increase this protection.

A different type of protection with the same aim is afforded by the wash or etch primer which consists of polyvinyl butyral pigmented with zinc chromate to which a solution of phosphoric acid is added immediately before use. This type of primer etches into the steel but as it is usually only about ⅓ mil in thickness, it gives protection only for a limited time. However, it does allow corrosion products to be removed more easily than if no primer had been used.

Zinc-rich epoxies are porous and protect the steel by cathodic protection. To achieve this the zinc particles must be in direct contact with the steel and each other and the dry film must therefore contain about 95 per cent zinc. However, it has been possible to reduce this percentage to 80–85 per cent with the recently available fine-particle zinc dusts (2–3 microns average diameter). Under normal conditions these paints are touch dry in two minutes at ½ mil thickness. Full cure takes 24 hours. There is no advantage in putting on a thicker coating than is recommended by the manufacturer. The criticism has been made of this type of primer that it blisters some time after overcoating, especially in locations where it is continuously under water. It is claimed that this can be overcome by allowing the primer to weather, when the formation of reaction products between steel and zinc blocks the pores in the primer. Minor scratches on the coating will be protected cathodically provided they do not expose too great a steel surface.

Welding on Shop Primers

When the use of shop primers began to increase, the Society was frequently approached by paint manufacturers regarding tests to determine whether a coating would be affected by welding. Although the maintenance of the quality of welding in the shipyard is the responsibility of the Surveyors to be determined by visual inspection supplemented by radiographs, there is perhaps something to be said for carrying out preliminary tests to ascertain whether or not, with the normal type of electrodes used, the welding would be affected and the following tests are at present usually called for in these circumstances:—

A V butt weld is made in ¾ in. or 1 in. plate with the faces of the V coated in accordance with the manufacturers instructions and a second coated specimen should be provided in which the coating is applied more liberally than recommended to take account of misapplication in practice. An uncoated specimen should also be prepared as a control and to be effective for this purpose, the welding must be free from defects. The welding and the tests should be done in the presence of Surveyors or alternatively, the work may be done

by a non-commercial body such as a University or an independent testing laboratory. The following tests are done on the welded plates: —

1. Radiograph—made according to BS.2600/62 Technique No. 2 with wire type IQI, e.g. DIN with an IQI sensitivity better than 2 per cent.
2. Photo-macrograph—from near each end and from centre of butt in test plate—may be actual size.
3. Face and reverse bend tests over a former of diameter equal to three times the plate thickness.
4. Impact tests on specimens prepared as given in P.207 of the Society's Rules to be carried out at room temperature and the results reported. The Charpy notch should be in way of the butt weld and at right angles to the plate surface.

In amplification of the foregoing, it is realised that, in practice, the Veed edges of butts will probably not be primed as the edges are prepared after priming, but the type of joint was chosen to give the maximum amount of welding on the coating. It is also the easiest joint to prepare and, therefore, any difference between the uncoated and the coated specimens should be obvious. In practice, the welds most likely to be made on a coating will be fillet welds and the criticism has sometimes been made that these are more liable to be affected by a primer when a double continuous automatic fillet weld is made. However, it is also understood that if the fillet weld on one side precedes that on the other side of the web then gases can escape, and there is less porosity.

If the results of the foregoing tests are satisfactory then the Society gives qualified approval and a letter to the effect that, with the particular electrode used, the welding was not affected by the primer.

Health aspects of welding on primers do not come within the province of the classification society, but it might be mentioned that any danger which may arise is due to the presence of zinc oxide. Zinc poisoning is unlike lead poisoning in that the effect is not cumulative, and attacks of "zinc chills" while unpleasant, are not serious. The epoxy binder also forms CO_2 and water on burning. The Ministry of Labour and Factory Inspectorate have specified that the maximum allowable concentration (MAC) of zinc oxide or iron oxide should not exceed 15 mg/cu. metre and that of carbon monoxide should not exceed 100 p.p.m. In the U.S.A. the amount of zinc oxide must not exceed 5 mg/cu. metre. The effect of the fumes from both these items may be reduced by keeping the coating thin and by adequate ventilation especially in confined spaces.

CATHODIC PROTECTION

General Principles

It has been shown earlier that the corrosion of steel is principally due to the fact that there are anodic and cathodic areas within the same plate causing corrosion of the former areas. Cathodic protection consists of arresting this "internal" corrosion by connecting to the structure a metal which is more electro-negative than either the anodic or cathodic areas of steel. This material therefore corrodes in preference to both these areas and in doing so the latter are protected. Alternatively, a direct current could be supplied to a suitable anode insulated from the cathode with the same effect, but from the safety aspect this cannot be done in cargo tanks, and we are therefore left with the use of galvanic anodes. The use of zinc strips for protecting a steel hull from electrolytic corrosion in the presence of a bronze propeller in the above manner is well known, but the application of these principles to cargo tanks is a comparatively recent phenomenon. So far as this country is concerned the first full-scale scientifically conducted experiment was in the tanker *Auris* and the results are described in a paper by Lamb, Mathias and Waite read to the N.E.C. Inst. in 1954.

As already stated, ship steel contains anodic and cathodic areas, but its average metal/electrolyte potential when freely corroding in sea water may be taken as $-0{\cdot}55$ V when measured against a standard $Cu/CuSO_4$ half cell, and to eliminate corrosion its potential must be reduced (polarised) to $-0{\cdot}85$ V. Therefore, for cathodic protection purposes we need material which will maintain the steel at least at the above level which necessitates a galvanic anode which has a more negative potential than $-0{\cdot}85$ V.

Instead of a $Cu/CuSO_4$ half cell as a standard, an Ag/AgC half cell may be used and the potential of protected steel then becomes $-0{\cdot}80$ V and all other figures are reduced by $-0{\cdot}05$ V. Similarly, a KC (calomel) half cell will result in a figure of $-0{\cdot}78$ V for protected steel. However, these differences in standards do not affect any calculations which are based on potential differences.

Although the term "low potential" as used in this paper refers to the actual negative value of the potential, magnesium and zinc (or aluminium) anodes may be referred to as high or low potential anodes respectively because of their different driving potentials.

Anode Materials

While there are many materials which have a more negative potential than steel polarised to $-0{\cdot}85$ V the only ones which need be considered in practice are magnesium, zinc and aluminium, other materials being unsuitable for various reasons, chiefly economic.

In the following paragraphs the potentials refer to a $Cu/CuSO_4$ half cell.

(a) Magnesium

This material has a specific gravity of 1·74 and a melting point of 650° C. It was the original anode material for use in cargo tanks and in the usual alloys it has a potential of $-1{\cdot}55$ V. The theoretical value of current capacity of 1,000 amp. hours/lb. is reduced in practice in sea water due to the formation of local corrosion cells to about 500 amp. hours/lb. (17·5 lb./amp. year), i.e. an efficiency of 50 per cent. However, high purity magnesium anodes may have an output of 700 amp. hours/lb. (12·5 lb./amp. year). The self, or parasitic, corrosion which occurs at the surface of magnesium anodes makes it self cleaning when contaminated by crude oil. The composition of the magnesium alloy vitally affects its performance, and most published figures limit the iron content to 0·003 per cent, nickel to below 0·003 per cent, with the addition of manganese to at least 0·15 per cent.

Because of its low potential magnesium tends to over protect the steelwork in its immediate vicinity by lowering the potential of the latter to as little as $-1{\cdot}2$ V. Potentials lower than $-1{\cdot}05$ V result in a reaction at the cathode which produces alkalinity and causes the precipitation of calcium carbonate and magnesium hydroxide. This forms a resistant film on the metal surface which reduces the galvanic current

in the vicinity of the anode, and this, together with the low anode potential, gives a large current throw, i.e. one anode will protect a large area of material. In addition, the calcareous film formed by magnesium anodes can protect the tank surface from atmospheric corrosion when the tanks are empty. To limit over protection near the anode, magnesium anodes usually stand well clear of the structure. Hydrogen is also evolved by the above reaction but this is probably no more hazardous than the usual tanker cargoes, except that it must be realised that this gas is being released when the ship is in ballast and therefore pressure vacuum valves in the vapour lines or tank lids should be open.

From experiments carried out by the Safety in Mines Research Establishment and others it has been known for some time that magnesium can produce an incendive spark if it strikes or is struck at an angle by rusty steel, and that quite low energy valves will produce this effect, e.g. there is a 50 per cent probability of incendive sparking in a 6·4 per cent methane/air mixture with magnesium alloys containing 93 per cent magnesium when the impact energy is 90 ft./lb. and 90 per cent probability when the impact energy is 200 ft./lb.

Over the last ten years there have been seven cases, out of a total number of 119, of explosions in tankers, known to the Society, where the cause of the explosion has been attributed to an anode, or part of an anode, failing in a tank, or being struck by a falling object. Not all of these cases concerned ships classed with the Society and therefore it is not possible to state what percentage of the 119 ships had anodes fitted, or the percentage of tankers as a whole so equipped. It is, of course, difficult when an explosion has occurred to trace its origin since the fact that parts of anodes are found in the bottom of the tank may be due to the explosion. It is possible to minimise these dangers by proper design of anodes and fittings, a suitable location and adequate inspection, with all of which the Society has concerned itself in classed ships since 1961. Nevertheless, it has been considered advisable in these circumstances, to ban the use of magnesium anodes in cargo/ballast tanks although they may still be used for permanent ballast tanks in tankers.

(b) Zinc

Zinc has a specific gravity of 7·1 and a melting point of 420° C. Anodes made of this material are at present the most popular alternative to magnesium. The potential is −1·1 V and the theoretical value of the current capacity is 372 amp. hours/lb., and at an efficiency of 95 per cent this becomes 350 amp. hours/lb. (25 lb./amp. year). Due to its high specific gravity a given volume of zinc will produce three times the amp. hours of the same volume of magnesium. As the potential is much nearer that of polarised steel, an individual anode is not capable of protecting such a large area and many more smaller zinc anodes will therefore be required than would be necessary with magnesium and this may lead to greater installation costs. Zinc presents no spark hazard and the volume of hydrogen released by the process is negligible. Ordinary commercial zinc as used in the past for protection at the sterns of ships was not very effective and this was due to the iron content which led to the formation of a hard corrosion product on the surface and subsequent passivation. Zinc containing more than 0·0014 per cent iron is therefore unsuitable. High purity zinc (99·99 per cent) does not suffer from this defect nor do various alloys of zinc containing small percentages of mercury or aluminium and cadmium which have been specially formulated as anode material, and these additions are also claimed to improve the protection characteristics in black oil.

(c) Aluminium

Aluminium has a specific gravity of 2·7 and a melting point of 660° C. It may have potentials varying between −1·05 V (aluminium/zinc alloy), to −1·4 V (aluminium/tin alloy). The theoretical value of the current capacity is 1,350 amp. hours/lb., but this is not attained in practice and efficiencies of 67 per cent, corresponding to 900 amp. hours/lb. (9·8 lb./amp. year), are at present obtained for aluminium zinc/alloys and an efficiency of 33 per cent, i.e. 450 amp. hours/lb. (19·5 lb./amp. year), is obtained for the aluminium/tin alloys. The aluminium/zinc alloys are the most commonly used because of their better efficiency and their cathodic protection characteristics are therefore very similar to zinc, but anodes of a given volume are much lighter. Aluminium anodes present a spark hazard, but experiments indicate this to be at most a quarter of that for magnesium. Having regard to the fact that many tankers are fitted with aluminium heating coils, and there has never been a suggestion that these might constitute an explosion hazard, the Society does not contemplate any action restricting their use. However, care should be taken with regard to their location and anodes of this material must be located clear of tank hatches and Butterworth cleaning openings, unless protected by adjacent structure. The U.S. Coast Guard have placed restrictions on the maximum height at which aluminium anodes may be located, and this corresponds to a maximum potential energy of 200 ft.lb. in free fall. The anodes on horizontal stringers and girders are unaffected by this provision if they are situated on the web plates. The volume of hydrogen given off by aluminium/zinc anodes is negligible, but no information is available regarding aluminium/tin alloys. Aluminium anodes are self cleaning by shedding of self corrosion products and this is an advantage in black oil carriers.

Research is continually going on with the object of improving the efficiency of aluminium alloys and if one can be developed having a somewhat lower potential than zinc and yet with an efficiency in excess of 80 per cent then this will have great advantages as a cathodic protection material.

Design of Cathodic Protection Systems

The design of cathodic protection systems for cargo/ballast tanks is based on a combination of theory and experience and, in this, as in so many problems connected with shipbuilding, the latter is of great importance. Such being the case, those firms which have had longest experience with many opportunities to check the effectiveness of previous installations, may be expected to design the most efficient systems. Although it does not follow that the most efficient system is the one with the least initial cost, it will be the cheapest in the long run. Most firms have considerable experience with magnesium anodes but the use of zinc or aluminium anodes is of comparatively recent origin. Nevertheless, some firms have more experience than others with these newer materials.

The basic problem is the supply of the minimum number of anodes which will be sufficient for protection purposes together with their distribution over the structure. This may also be stated as supplying the minimum current for protection purposes. The amount of current which will flow in association with a given difference in potential between anode

and structure will depend mostly on the length of the path which the current will have to travel in the electrolyte, and the shorter this distance the less the current will be affected. If the current paths were the same for all parts of the tank then a uniform degree of protection could be obtained. However, in a complex structure like a cargo tank, the current may have to travel a number of different paths to reach the various parts and this, coupled with the fact that the anodes consist of separated items located fairly close to the structure, means that it is not possible to achieve a uniform protective potential over the whole of the steel work. Some parts will be over protected near the anode in order to achieve adequate protection further away. This variation in potential will, however, be less with magnesium anodes which can be placed well clear of the structure.

Cathodic protection requirements may be measured by installing a temporary anode and measuring the output and structure/electrolyte potential at various distances from the anode, but as adjacent anodes have a cumulative protective effect on the area midway between them one would eventually be in the position of having to install a complete system in a typical transverse bay before the measurement would give an accurate picture.

It is customary in these circumstances to design on a basis of average current density (mA/ft.^{2}) over the whole of the structure to be protected, and this will be higher than the minimum current density for protecting specific small areas.

When a structure has reached the protective potential it only requires a comparatively small current to keep it polarised, about 3–4 mA/ft.^{2} being sufficient for cargo/ballast tanks in black oil trades and 5–6 mA/ft.^{2} for cargo-ballast tanks in the white oil trades assuming magnesium anodes are fitted. However, if such current densities were used initially, it would take a long time to achieve polarisation, and it is therefore necessary to also consider the current density in relation to unpolarised steel work.

For magnesium anodes the usually quoted figures are 10 mA/ft.^{2} for cargo/ballast tanks in black oil trades, 20 mA/ft.^{2} for white oil trades, and 15 mA/ft.^{2} for permanent ballast tanks. The reason for the lower figure for black oil is that the structure is partly protected by the wax film which is present in this trade and, therefore, on the basis of the whole area less current is needed for full protection. Tanks carrying white oil will probably lose any protective deposit quicker than those carrying water ballast only, and therefore the figures for these tanks are higher than those for black oil and permanent ballast tanks.

The area of the structure used in calculations for white oil/ballast tanks is usually the entire superficial area of tank sides and bottom including stiffeners, etc., but excluding any coated areas. The deck head may also be included if an attempt is made to protect this area. In black oil/ballast tanks it is probably only necessary to take into account the horizontal surfaces and those vertical surfaces which are within the protective range of the anode, and this latter will depend on the anode material.

With constant anode to structure distances, the flow of current will vary with the potential difference between the anode and structure, and an example is given below showing the effect of using different anode materials:—

Freely corroding steel potential	=	−0·55 V
Steel polarised to protection level	=	−0·85 V
Magnesium	=	−1·55 V
Zinc	=	−1·10 V

Differences in potential between anode and structure (V)

	Steel corroding	Steel just polarised	Probable final steady state
Mg	1·00	0·70	0·35
Zn	0·55	0·25	0·10

All potentials refer to $Cu/CuSO_4$ half cell and figures for the more commonly used aluminium anodes will be similar to zinc.

It will be observed that when the steel is just polarised the potential difference using magnesium is three times that of zinc, and this ratio is maintained in the final steady state although the potential differences are then much lower resulting in a low output from the zinc anodes. In these conditions an increase in steel potential of 0·1 V will double the output from the zinc anode but will only increase the output of the magnesium anode by a third. Zinc and aluminium anodes of similar potential are therefore said to be self regulating.

It will also be noticed that the ratio of the differences in potential between steel in the unpolarised and final steady condition is about 3 : 1 for magnesium and this is the same as the ratio of recommended initial to final current densities referred to earlier. For zinc the ratio of potential differences under similar conditions is about 5 : 1 which would suggest initial current densities of 15–20 mA/ft.^{2} for this material in black oil. Such figures have, in fact, been suggested but the comparison is not necessarily a correct one since it does not appear to take into account that the basic data for magnesium are based on average current density and this average is based on potential differences between anode and structure which are different for the two materials, e.g. for magnesium the potential difference may vary between 0·35 V near the anode to perhaps 0·5 V or more midway between adjacent anodes, whereas for zinc these figures are probably 0·1 V and 0·2 V. As current flow and therefore current density depend on potential differences, it may not follow that figures for average current density with magnesium are directly applicable to zinc although other factors may in the end result in similar figures being used. These factors may be the effect of obstructions on the throw of the anode and their behaviour in black oil.

Taking the first point, the current path from an anode behaves somewhat in the manner of a light beam in that any obstruction may cause a "shadow" in which the protective current will be reduced. Magnesium anodes standing well clear of the structure will therefore be less affected by upstanding items than zinc or aluminium anodes whose height is limited by their lower driving potential. Regarding the second aspect, the behaviour of anode materials in black oil, magnesium anodes are capable of effective protection through a film of oil due to the nature of the self corrosion product which occurs on the surface, but these characteristics are not so evident in zinc and aluminium. The means adopted to overcome this difficulty with the latter materials are the introduction of special alloying elements, the selection of anode shapes and locations which will obtain the maximum cleaning effect from Butterworthing, or by increasing the number of anodes to allow for loss in output. In one experiment with zinc anodes containing mercury, it was estimated that the anode potential was reduced by 0·07 V due to contamination by crude oil. This is a large percentage when one considers that the difference in potential of zinc to steel which is just at protection level is only 0·25 V. A proportionate increase in a

number of anodes, i.e. about 50 per cent, could therefore be made to allow for crude oil pollution and although this would be initially more expensive, it would have the effect of prolonging the anode life. Recent practice has been, however, to give a 25 per cent increase in initial current densities for zinc anodes in crude oil as compared with magnesium anodes.

As stated previously, the design of cathodic protection systems is best left to experts, but there are formulæ which can be used as a basis for comparison.

The current flowing in the cathodic protection circuit may be derived from the usual formula: —

$$\text{Current (amps)} = \frac{\text{Difference in potential (volts)}}{\text{Total resistance (ohms)}} \quad (1)$$

Difference in potential would be the anode material potential minus the structure potential in various conditions as given earlier. The current can, therefore, be determined if the resistances in the circuit are known. The total resistance is composed of the resistance of the anode and structure, the interface resistance of the metal/electrolyte boundary and the resistance of the electrolyte itself. In practice, only the latter is of importance provided the surface of the structure and anode is uncoated or not contaminated by oil or polarisation products.

Formulæ for the resistance of anodes of various shapes in an infinite electrolyte have been derived by Prof. Dwight, but we need only consider two simple shapes, the sphere and the rod. In the following formulæ,

R = the resistance in ohms,

r = the radius of the phere or rod in cms.,

ρ = the resistivity of sea water in ohm cms.,

L = the length of the rod in cms.

For the sphere,

$$R = \rho \cdot \frac{1}{2\pi r}$$

For a rod,

$$R = \frac{\rho}{2\pi L}\left(\log_e \frac{2L}{r} - 1\right) \quad (3)$$

The resistivity of sea water varies between 25–30 ohm cms, and where water of specific gravity less than 1·02 has to be used for ballast it should be replaced by sea water as soon as possible, since brackish water has a considerably increased resistivity (the resistivity of tap water varies from 1,000–5,000 ohm cms).

Rectangular block or long thin anodes of non-circular cross section may be considered on the basis of an equivalent cylinder having the same volume and length as the anode, without great loss of accuracy.

An approximation for the fact that the anodes are not located in an infinite electrolyte can be made by using the assumption that the steelwork forms part of an enclosing sphere or cylinder as the case may be, having a radius of r_1 equal to the "stand off" distance of the anode from the plating (not stiffeners). Formula (2), for a sphere, therefore becomes,

$$R = \frac{\rho}{4\pi}\left(\frac{1}{r} - \frac{1}{r_1}\right) \quad (4)$$

and formula (3), for a rod, becomes

$$R = \frac{\rho}{2\pi L} \log_e \frac{r_1}{r} \quad (5)$$

Although these resistances are for individual anodes and protection is increased by the principle of super-position where there are a number of anodes spaced reasonably closely fore and aft and athwartships (say not less than an anode length between rows), they may be used for comparison purposes with similar lay-outs. Fig. 1 illustrates formula (5): —

The anode life will depend on the average current output in service which will depend on the frequency of ballasting, the period in ballast and the amount of tank cleaning, also the fact that the output will not be the same, due to its reduced dimensions, when the anode has been in service for some time. Having arrived at the average output per voyage by consideration of the initial and final output when the anode is new, and when it has been consumed to say 40 per cent of its original volume, the life, in years, can be determined from the product of say 80 per cent of the weight of the anode multiplied by the actual current capacity of the material in amp. hours/lb. divided by 8,760 (the number of hours in a year). This figure can then be corrected for the percentage of time in ballast, e.g. if the life of the anode by the above calculation is one year and the ballast time is 25 per cent then the anode will last four years. Although the consumption of the anode is proportional to the current delivered, the rate of consumption at any place on the surface of the anode will depend on the current density at that point. Current density, and therefore consumption, will be greater at points and corners and similar considerations apply to the structure, i.e. corners where the surfaces meet at more than 180°, such as edges of flanges, will corrode quicker than those where the corners meet at less than 180° such as the junction of stiffeners and plating. Conversely, the edges of flanges, etc., absorb current and are protected quicker than tank corners and the like. All anodes tend towards a spherical shape as they are consumed and changes in anode shape affect their resistance, elongated anodes being affected more than spherical ones.

It is obviously more convenient if anode life is designed on the basis of renewal at docking or special surveys, i.e. two- or four-year intervals. If the two-year period is adopted then arrangements might also be made to renew half the anodes on each occasion, thus maintaining more even protection.

It has been found in practice that for cathodic protection to be effective a tank must be in ballast for at least 20 per cent of the time and if this percentage can be increased to 25 per cent so much the better. If the ballast voyages are short, requiring rapid re-polarising of the surface on each occasion, then the number of anodes will require to be increased to cover for this, even though the percentage of time does not fall below 20 per cent. It has been suggested that magnesium anodes will require no increase over normal requirements if the ballast voyages are three days or more, but that this figure should be five days for zinc or aluminium. If the voyages are of less duration then the current densities given previously should be increased by 10 per cent.

Tanks used only for water ballast have about 40 per cent of the time in ballast and as this may mean quicker consumption of anodes, their size must be adjusted accordingly.

Due to the necessity for tank cleaning and the fact that certain tanks remain empty in ballast because adequate draught can be obtained without filling all the tanks, it is not possible to reach the minimum figure of 20 per cent for every tank. Cathodic protection is therefore usually confined to either wing or centre tanks. In addition, unless scrupulous

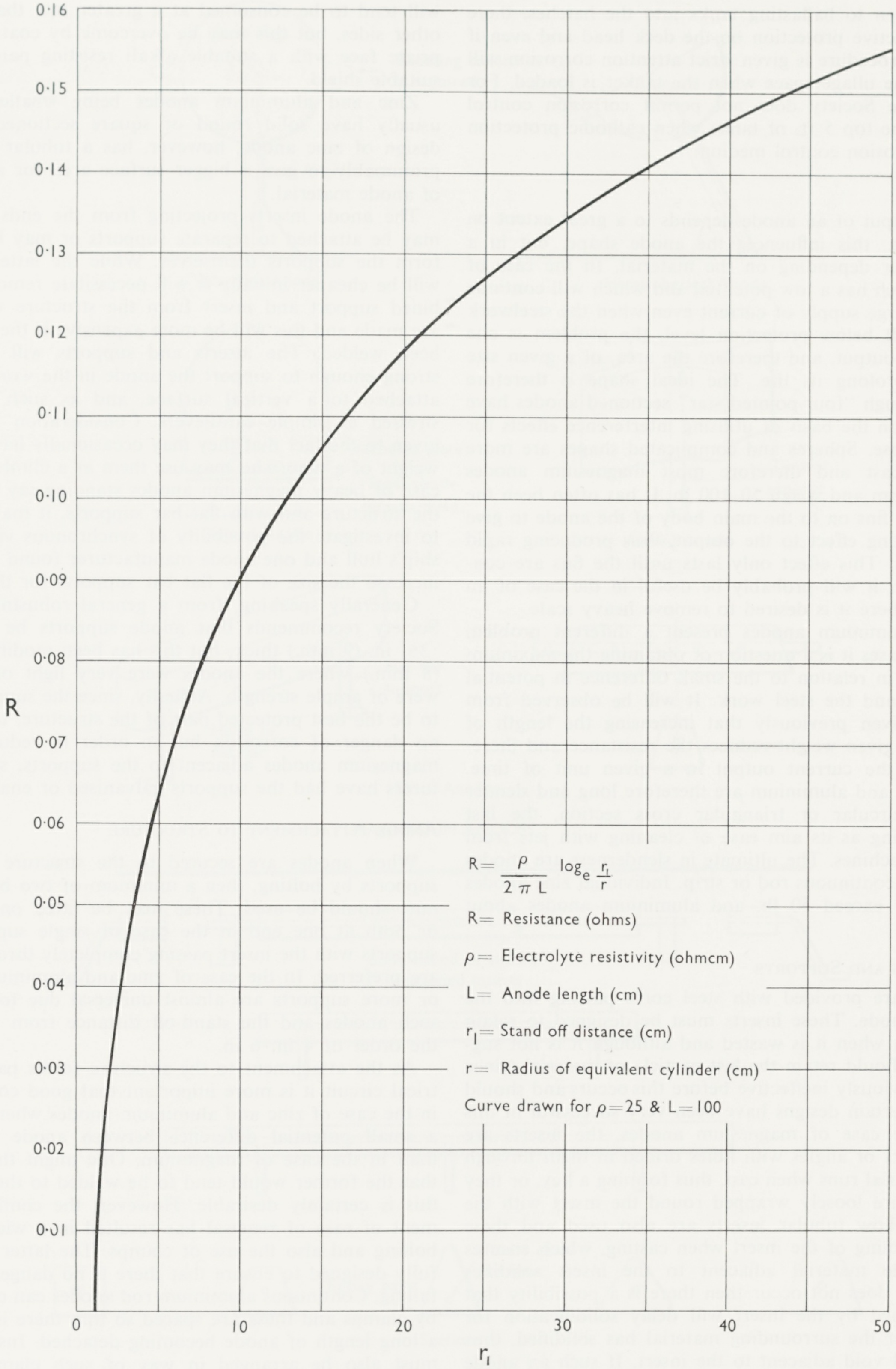


FIG. 1

Resistance of anode in electrolyte.

attention is given to ballasting tanks into the hatches, there will not be effective protection on the deck head and even if the foregoing procedure is given strict attention corrosion will still occur in the ullage space when the tanker is loaded. For this reason, the Society does not permit corrosion control reductions in the top 5 ft. of tanks when cathodic protection is the only corrosion control medium.

Anode Shape

Since the output of an anode depends to a great extent on its surface area, this influences the anode shape, but in a different manner depending on the material. In the case of magnesium which has a low potential and which will continue to produce a large supply of current even when the steelwork potential is well below protection level, the problem is one of limiting the output, and therefore the area, of a given size of anode to prolong its life. The ideal shape is therefore spherical, although "four-pointed star" sectioned anodes have been designed on the basis of utilising interference effects for the same purpose. Spheres and complicated shapes are more expensive to cast and therefore most magnesium anodes are in block form and weigh 50–100 lb. It has often been the practice to cast fins on to the main body of the anode to give an initial boosting effect to the output, thus producing rapid tank protection. This effect only lasts until the fins are consumed although it will probably be useful in the case of an existing ship where it is desired to remove heavy scale.

Zinc and aluminium anodes present a different problem since in these cases it is a question of obtaining the maximum current output in relation to the small difference in potential between them and the steel work. It will be observed from the formulæ given previously that increasing the length of an anode of a given weight reduces the resistance and therefore increases the current output in a given unit of time. Anodes of zinc and aluminium are therefore long and slender with square, circular or triangular cross section, the last mentioned having as its aim ease of cleaning with jets from Butterworth machines. The ultimate in slenderness are anodes consisting of a continuous rod or strip. Individual zinc anodes do not usually exceed 50 lb. and aluminium anodes about 30 lb.

Anode Inserts and Supports

All anodes are provided with steel cores passing into the body of the anode. These inserts must be designed to retain the anode even when it is wasted and although it is not suggested that it should retain the last particle of material (since the anode is obviously ineffective before this occurs and should be renewed), certain designs have been very successful in this respect. In the case of magnesium anodes, the inserts are usually flat bars or angles with holes drilled in them through which the material runs when cast, thus forming a key, or they may have a wire loosely wrapped round the insert with the same aim. Hollow tubular inserts are also used and these allow rapid cooling of the insert when casting, which ensures that the anode material adjacent to the insert solidifies rapidly. If this does not occur then there is a possibility that the heat retained by the insert will delay solidification for some time after the surrounding material has solidified, thus leaving a small void adjacent to the insert. If such an anode is not renewed in good time then corrosion products in the void can cause the anode to split off the insert. If magnesium anodes must perforce be arranged somewhat close to the structure, then the material on the side close to the structure will tend to be consumed at a greater rate than that on the other sides, but this may be overcome by coating the appropriate face with a suitable alkali resisting paint or fitting a suitable shield.

Zinc and aluminium anodes being smaller and lighter usually have solid round or square sectioned inserts. One design of zinc anode, however, has a tubular core which is presumably to give a bigger surface area for a given weight of anode material.

The anode inserts projecting from the ends of the anode may be attached to separate supports or may be extended to form the supports themselves. While the latter arrangement will be cheaper initially it will necessitate removing the combined support and insert from the structure when renewals are made and this will be more expensive if the supports have been welded. The inserts and supports will require to be strong enough to support the anode in the worst attitude, i.e. attached to a vertical surface, and as such they may be stressed as simple cantilevers. Consideration might also be given to the fact that they may occasionally have to carry the weight of a man who may use them as a climbing aid. In the case of heavy magnesium anodes standing say 15 in. clear of the structure and with flat bar supports, it may be necessary to investigate the possibility of synchronous vibration of the ship's hull and one anode manufacturer found it necessary to increase the size of the flat bar supports for this reason.

Generally speaking, from a general robustness aspect, the Society recommends that anode supports be not less than ·36 in. (9 mm.) thick, but this has been modified to 5/16 in. (8 mm.) where the anodes were very light or the supports were of ample strength. Actually, since the supports are likely to be the best protected part of the structure, there should be no danger of corrosion but in order to reduce wastage of magnesium anodes adjacent to the supports, some manufacturers have had the supports galvanised or enamelled.

Anode Attachment to Structure

When anodes are secured to the structure or to welded supports by bolting, then a minimum of two bolts with locknuts should be used. These may be fitted one at each end or both at one end in the case of single supports. Double supports with the insert passing completely through the anode are preferred. In the case of zinc and aluminium anodes two or more supports are almost universal due to the length of such anodes and the stand-off distance from stiffeners is of the order of 4 in.–6 in.

As the attachment to the structure forms part of the electrical circuit it is more important that good contact be made in the case of zinc and aluminium anodes where there is only a small potential difference between anode and structure, than in the case of magnesium. One might therefore expect that the former would tend to be welded to the structure and this is certainly desirable. However, the conflicting requirement of ease of renewal has resulted in a wide adoption of bolting and also the use of clamps. The latter must be carefully designed to ensure that there is no danger of the anode falling. Continuous aluminium rod anodes can only be secured by clamps and these are spaced so that there is no danger of a long length of anode becoming detached. Insulation sleeves must also be arranged in way of such clamps to prevent wastage of the anode at this point.

When anode inserts or supports are welded to the structure care should be taken to arrange the welding clear of possible points of stress concentration such as ends of brackets. The

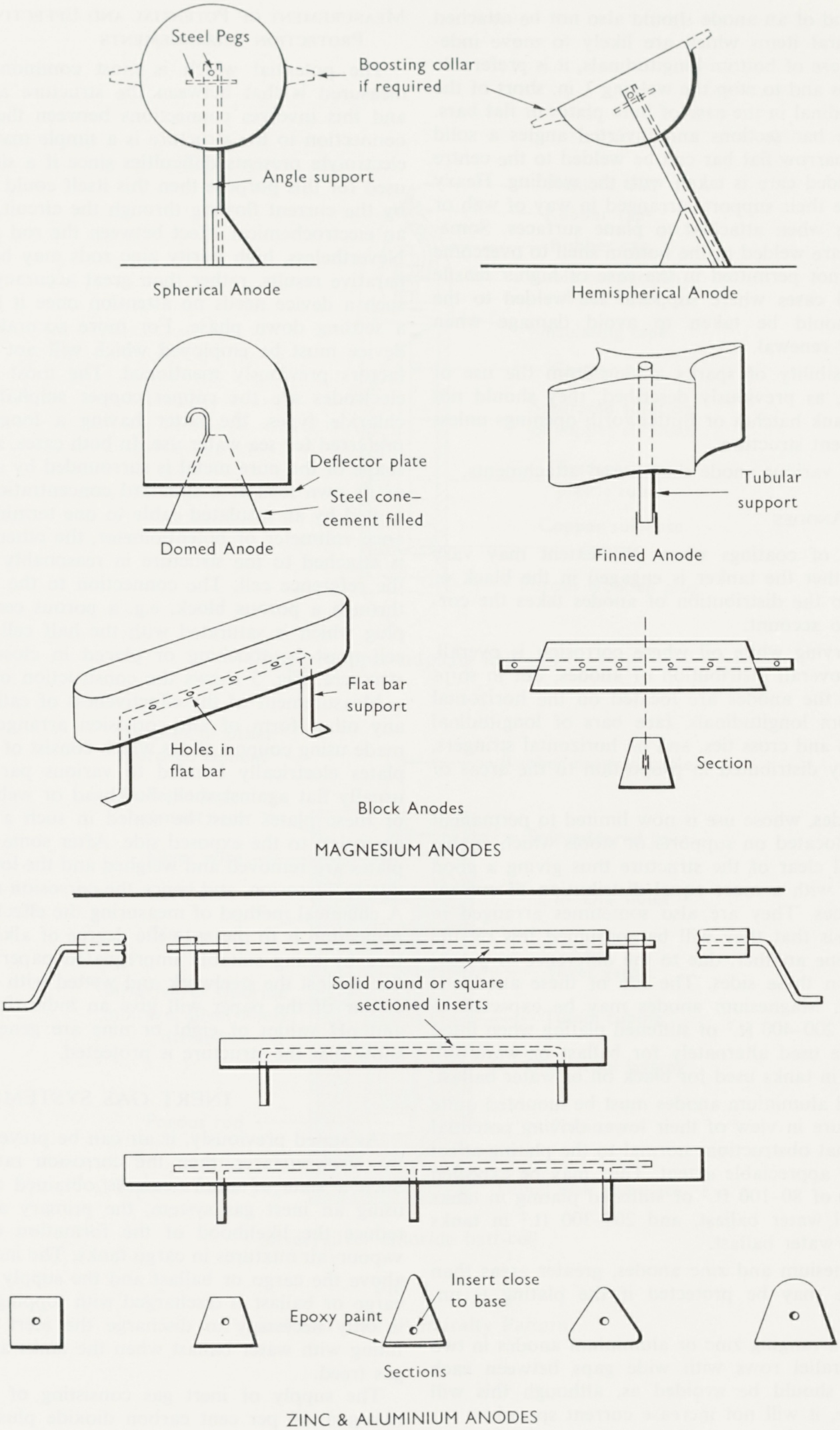

Steel Pegs
Boosting collar
if required
Angle support
Spherical Anode
Hemispherical Anode
Deflector plate
Steel cone–
cement filled
Domed Anode
Tubular
support
Finned Anode
Flat bar
support
Holes in
flat bar
Section
Block Anodes
MAGNESIUM ANODES
Solid round or square
sectioned inserts
Insert close
to base
Epoxy paint
Sections
ZINC & ALUMINIUM ANODES

FIG. 2

supports at each end of an anode should also not be attached to separate structural items which are likely to move independently. In the case of bottom longitudinals, it is preferable to weld to the webs and to stop the welding 1 in. short of the edge of the longitudinal in the case of bulb plates or flat bars. In the case of tee bar sections and inverted angles a solid round support or narrow flat bar can be welded to the centre of the flange provided care is taken with the welding. Heavy anodes should have their supports arranged in way of web or bulkhead stiffening when attached to plane surfaces. Sometimes strip anodes are welded to the bottom shell to overcome pitting but this is not permitted in the case of higher tensile shell plates. In all cases where supports are welded to the structure, care should be taken to avoid damage when removing them for renewal.

Due to the possibility of sparks arising from the use of aluminium anodes, as previously described, they should not be located under tank hatches or Butterworth openings unless protected by adjacent structure.

Fig. 2 illustrates various anode shapes and attachments.

Distribution of Anodes

As in the case of coatings where the extent may vary depending on whether the tanker is engaged in the black or white oil trades, so the distribution of anodes takes the corrosion patterns into account.

For tankers carrying white oil where corrosion is overall, there must be an overall distribution of anodes, but in ships carrying black oil the anodes are located on the horizontal surfaces, i.e. bottom longitudinals, face bars of longitudinal girders, transverses and cross ties, and on horizontal stringers, the numbers evenly distributed in proportion to the areas of the items.

Magnesium anodes, whose use is now limited to permanent ballast tanks, are located on supports or stools which enable them to stand well clear of the structure thus giving a good spread of current, with a more equal distribution of current demand on all sides. They are also sometimes arranged in ladders on the basis that they will be consumed less on the sides adjacent to one another, due to the difference in potential being lower on these sides. The life of these anodes is thereby prolonged. Magnesium anodes may be expected to protect an area of 200–400 $ft.^2$ of stiffened plating when fitted in tanks which are used alternately for ballast or white oil, and 700–1,000 $ft.^2$ in tanks used for black oil or water ballast.

Zinc anodes and aluminium anodes must be mounted quite close to the structure in view of their lower driving potential but not so close that obstructions normal to the plating affect the current to any appreciable extent. They may be expected to protect an area of 80–100 $ft.^2$ of stiffened plating in tanks used for white oil/water ballast, and 200–300 $ft.^2$ in tanks used for black oil/water ballast.

With both magnesium and zinc anodes, greater areas than those given above may be protected if the plating is unstiffened.

The practice of arranging zinc or aluminium anodes in two closely spaced parallel rows with wide gaps between each parallel grouping should be avoided as, although this will prolong anode life, it will not increase current spread.

Location of anodes should also take into account accessibility for inspection and ease of renewal, and avoidance of mechanical damage during tank cleaning and washing.

Measurement of Potential and Effectiveness of Protection Arrangements

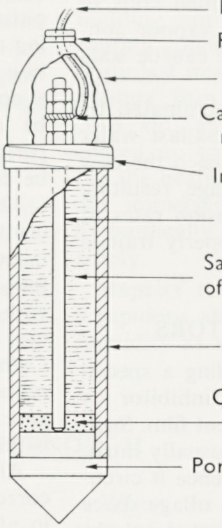
The potential which is most commonly required to be measured is that between the structure and the electrolyte, and this involves connections between these two items. The connection to the structure is a simple matter but that to the electrolyte presents difficulties since if a simple steel rod was used for this purpose then this itself could be partly polarised by the current flowing through the circuit, or there might be an electrochemical effect between the rod and the electrolyte. Nevertheless, high purity zinc rods may be used where comparative results, rather than great accuracy, are required and such a device needs no attention once it has passed through a settling down phase. For more accurate measurements, a device must be employed which will not be affected by the factors previously mentioned. The most common reference electrodes are the copper/copper sulphate and silver/silver chloride types, the latter having a longer life, and being preferred for sea water use. In both cases, a rod or some other shape of the pure metal is surrounded by a saturated solution of its own ions at a standard concentration. The rod is connected by an insulated cable to one terminal of a high resistance voltmeter or potentiometer, the other terminal of which is attached to the structure in reasonably close proximity to the reference cell. The connection to the electrolyte is made through a porous block, e.g. a porous ceramic or a wooden plug which is saturated with the half cell solution. The half cell must be touching or placed in close proximity to the structure. Fig. 3 shows the construction of typical half cells.

Measurement of the effectiveness of cathodic protection or any other form of anti-corrosion arrangements can also be made using coupon plates which consist of accurately weighed plates electrically bonded to various parts of the structure usually flat against shell, bulkhead or web plating. The back of these plates must be sealed in such a way as to restrict corrosion to the exposed side. After some time in service the plates are removed and weighed and the loss in weight, if any, due to corrosion, and hence the corrosion rate, may be found. A chemical method of measuring the effectiveness of cathodic protection is to measure the degree of alkalinity of the structure by using suitably impregnated papers which are placed flat against the steelwork and wetted with distilled water. The colour of the paper will give an indication of the alkalinity and pH values of eight or nine are generally considered to show that the structure is protected.

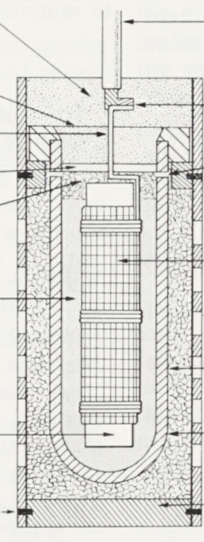
INERT GAS SYSTEMS

As stated previously, if air can be prevented from reaching the steel surfaces, then the corrosion rate can be reduced. Such a state of affairs can be obtained as a by-product of using an inert gas system, the primary aim of which is to reduce the likelihood of the formation of explosive petrol vapour/air mixtures in cargo tanks. The inert gas is introduced above the cargo or ballast and the supply is increased as the cargo or ballast is discharged with topping up as required. It is only necessary to discharge the inert gas by completely filling with water ballast when the tanks are to be cleaned or gas freed.

The supply of inert gas consisting of about 83 per cent nitrogen, 14 per cent carbon dioxide plus oxygen and other gases is obtained from the flue gas from the ship's boilers or may come from a separate inert gas generator if there is no boiler, or the boiler supply is insufficient. The flue gas must



Copper/copper sulphate half-cell.



Silver/silver chloride half-cell.

FIG. 3

Typical half-cells (Admiralty Pattern).

not contain more than 4 per cent oxygen and this is controlled by the amount of air supplied to the combustion chamber. Solid impurities are removed by passing the gas through a salt water scrubber. Depending on the gas temperature leaving the scrubber, water vapour containing sulphur dioxide may be present to a greater or less degree. To reduce the water vapour and sulphur dioxide, both of which could cause tank corrosion, the gas may then be passed over chilled coils to further reduce the dew point and therefore the vapour content, or it may pass through a lower temperature caustic soda spray to remove the remaining sulphur dioxide.

It will be appreciated that corrosion is not eliminated by this method since oxygen is always present in ballast water and, in addition, the ambient temperature may reach the dew point of the flue gas in the tanks during the voyage, resulting in condensation in empty tanks. However, corrosion rates of 20 per cent of normal can be obtained with properly trained personnel.

OIL AND WATER SOLUBLE INHIBITORS

The rate of corrosion may be reduced by adding a special fluid to refined oils which acts as a corrosion inhibitor by plating out on the surface to form a water repellent film. Such a fluid can be added at the refinery but is more usually introduced into the loading line on the ship from whence it circulates to the cargo tanks. Since there is always an ullage space at the top of the cargo it will not normally protect the deckheads and upper parts of bulkheads but it may also be floated on top of ballast water and the tanks subsequently pressed up into the coamings when the deckheads will also be protected. On the other hand, such a procedure means introducing ballast water into tanks which might otherwise not need ballasting. When used in ballast tanks, care must be taken to strip the tanks clean since otherwise the concentration of inhibitor will build up with subsequent cargoes and may exceed permissible limits set by the shipper. Certain oil companies have had good experience with this method but as the use of the inhibitor coincided with changes in operation, such as minimum washing, avoidance of slack ballast tanks and closure of empty tanks which would themselves reduce corrosion, it is difficult to ascertain what proportion of the improvement was due to the inhibitor alone.

Care is necessary to ensure that the correct proportion of inhibitor is added and this, together with the ballasting procedure, involves careful crew instruction. The system has the advantage of being economic to operate.

So far as is known, it has not been applied to crude oil carriers.

Water soluble inhibitors act in a similar manner but they are added to ballast water.

DEHUMIDIFICATION

This consists of reducing the relative humidity in the tanks to less than 60 per cent by warm air mechanical ventilation. It cannot be applied to ballast tanks containing water.

CONCLUSION

As has been mentioned earlier, coatings are the only means of corrosion control which can prevent corrosion and can definitely be seen to do this, but the cost exceeds that of other systems.

The other methods described can generally be seen to be retarding corrosion due to the absence of heavy scale or pitting and, where cathodic protection is fitted, the functioning of the system may be checked by observing the consumption of the anodes. Where there is some doubt as to whether a corrosion control system is doing its job properly, it may be advisable to check the thickness of certain members periodically and ultrasonic thickness gauging enables this to be done rapidly and accurately.

The slowing down of the corrosion rate may well be sufficient for the owner's purpose since a 50 per cent reduction in corrosion rate will double the life of the tanks. In actual fact, corrosion rates can be reduced by more than 50 per cent with the alternative systems mentioned, although this may not apply to every tank or every part of individual tanks. Cathodic protection, for instance, can achieve an 80 per cent reduction in corrosion rates. Some systems place more reliance for their effectiveness on the crew than others, and this is possibly a disadvantage.

All things considered, it seems likely that the most popular corrosion control system will utilise coating of the deckhead in all tanks with either additional coating of specified items, or the use of one of the alternative systems for the remainder of the tanks. Combinations of coatings with cathodic protection are already in use, and even in those cases where the tank bottoms have been fully coated, anodes have been used to minimise the effect of paint breakdown.

ACKNOWLEDGMENTS

The Author is indebted to Messrs. British Paints Ltd., F. A. Hughes & Co. Ltd., and Wilson Taylor & Co. Ltd. for their constructive criticisms during the preparation of this paper.

BIBLIOGRAPHY

"Cathodic Protection", by J. A. Morgan, M.A., published by Leonard Hill.

"Corrosion", edited by L. L. Shrier, published by Newnes.

"Marine Corrosion", by J. M. Murray, Lloyd's Register Staff Association 1952/53.

"Cathodic Protection of the Interior of Cargo Compartments in Oil Tankers", by Lamb, Mathias & Waite, N.E.C.I. 1954.

"The Preservation of Oil Tanker Hulls", by Lamb & Mathias, N.E.C.I. 1958.

"The Surface Preparation & Protection of Ship Plate", by Wilson & Zonsveld, N.E.C.I. 1962.

"Clean Oil Tanker Protection by Oil Soluble Inhibitors", by Malcolmson & Quimby, S.N.A.M.E. 1962.

APPENDIX I

Protective Coatings for Vegetable Oil Tanks

The above are used both to eliminate corrosion and to ease cleaning between successive shipments of vegetable oils. The choice of a particular coating is a matter for the owner, but he must also have the agreement of the shipper. To minimise difficulties with the latter, the Society has agreed to circulate to the Surveyors at ports concerned, details of any tests which a paint manufacturer may have had carried out by independent authorities relating to the effect, if any, such coatings have on the oils concerned.

While no set procedure has been laid down for such tests, they are usually on the following lines:—

Immersion of a coated plate in the various vegetable oils at, say 20° C. and 45° C. for a period of from four to six weeks. Comparison with control samples of oil stored under the same conditions should show no differences in the quality of the oils at the end of the tests, and the coating itself should also be satisfactory.

The ratio between the amount of liquid and the coated surface should bear some relation to that found in deep tanks and about 14 pounds of liquid per square foot of coated surface is satisfactory.

If the vegetable oil tanks are coated when the ship is building and the steelwork is then shot blasted and the coating applied under the proper conditions, then it will obviously last much longer. If blast cleaning has to be done on an existing ship, then care must be taken to remove heating coils, etc., as otherwise the steelwork will not be cleaned or coated in way of the supports. Special paints are available for the heating coils which will be satisfactory when the coils are immersed, but the latter should only be tested either hydraulically or by low pressure steam when the tanks are empty.

Repairs to coatings must be carried out with the same scrupulous attention to surface preparation, temperature and humidity as was required for the original coating.

APPENDIX II

External Cathodic Protection

Cathodic protection is also used externally to prevent corrosion and it is claimed that the paint performance is thereby improved. Where paint breakdown does occur, for example due to chafing, the anodes protect the bare steel and prevent the spread of the paint damage which would otherwise occur due to corrosion.

The protection may be obtained either by galvanic anodes or by an impressed current system. The former would generally employ zinc or aluminium anodes as, due to their self regulating characteristics, they will have a longer life than magnesium. More anodes will be located in the stern region than elsewhere, due to the presence of the propeller and the remainder will be located along the bilge. Some anodes may be arranged on the rudder. Anodes may be fitted in groups with the end units of streamline form, but, even so, they may add slightly to the hull resistance although this should be offset by the reduction in hull roughness. As such anodes are attached to the shell by welding their inserts, and when renewal is required the old inserts must be removed with possible damage to the shell, it is considered advisable to weld the inserts to small doublings which are themselves continuously welded to the shell in way of areas which are important from the longitudinal strength aspect, i.e. on the bilge strake of dry cargo ships within the area of 0·25L forward and aft of amidships, and, on the bilge strake of tankers within the length of the cargo tanks including the area within 0·25L aft of amidships. The anode inserts may be welded direct to the shell forward and aft of the above areas. In addition, they may be welded direct to the side shell amidships provided they are clear of the bilge radius and of special quality plating. Where a bilge keel is fitted the anodes should preferably be welded to it. Anode inserts should not be attached in way of butts or seams.

Where the impressed current system is installed this consists of supplying a low voltage d.c. current to permanent anodes of suitable long life material, e.g. platinised titanium. The supply cable passes through a watertight gland in the ship's side, the gland being enclosed in a watertight box. The cable may not pass through cargo oil tanks but may be led through a cofferdam or cargo pump room provided it is enclosed in a heavy gauge galvanised steel tube to a junction box on the open deck.

The anodes are situated in the centre of plastic insulating panels which reduce the amount of over protection in the vicinity of the anode and give greater current spread. For about 5 ft. around this panel and beneath it, the hull is usually blast cleaned and a coal tar epoxy paint applied to resist the stripping action (due to alkali formation) of the protective current near the anode.

Recommendatons regarding the fitting of doublings for securing studs of impressed current anodes are the same as for galvanic anodes, but these are unnecessary if, as is sometimes the case, the anodes are attached to a large continuously welded doubling, which forms the backing for the insulating shield.

Where it is necessary to lead a cable along the outside of the hull, e.g. from a cofferdam to an anode in way of the cargo tanks, the protective channel or angle containing the cable, which is permanently attached to the hull, may be welded direct to the shell by continuous welding.

Control devices are usually fitted to monitor the current to suit the protective requirements of the hull, since these are different when the vessel is stationary and under way. These devices use reference electrodes which necessitate a small hole in the shell.

Printed by Lloyd's Register of Shipping
at Garrett House, Manor Royal,
Crawley, Sussex, England

For Private Circulation amongst the Staff only

Lloyd's Register Staff Association

Session 1964-65

Paper No. 4

Discussion

on

Mr. O. M. Clemmetsen's Paper

CORROSION CONTROL

LLOYD'S REGISTER OF SHIPPING

71, Fenchurch Street, LONDON, E.C.3

The Author of this paper retains the right of subsequent publication, subject to the sanction of the Committee of Lloyd's Register of Shipping. Any opinions expressed and statements made in this paper and in the subsequent discussion are those of the individuals.

Discussion on Mr. O. M. Clemmetsen's Paper

CORROSION CONTROL

Mr. W. J. ROBERTS

The Author is to be congratulated on the comprehensive nature of this paper which should prove valuable to his colleagues in the Society.

Mr. Clemmetsen mentions investigations into this subject undertaken in the U.S.A., and some further notes in this respect might be of interest especially since the Society's Surveyors participated in them.

Corrosion in tankers has been studied by the American Petroleum Institute since 1927. Their investigations were interrupted by World War II, but were resumed in 1955 when the Tanker Corrosion Research Project was established, and a full-time co-ordinator appointed. Financial and technical support came from contributing tanker companies, The Bureau of Ships, Naval Research Paint Laboratory, M.S.T.S., Coast Guard and Classification Societies.

At the request of the A.P.I., Lloyd's Register at New York nominated Surveyors to the appropriate committees, and Mr. T. A. Simpson, Mr. E. Flynn and others attended many meetings over the years.

The programme envisaged the accurate measurement of the reduction in scantlings caused by corrosion in a number of ships so that diminution could be assessed. This was not so easy as it may sound because while considerable corrosion over the years can be gauged at periods such as Special Surveys, the measurement of the diminution over shorter periods, such as yearly intervals, to give consistent results was not so easy, and a good deal of preliminary investigation had to be carried out to select instruments and methods which would be effective. In particular, it was necessary to know not only the maximum depth of corrosion at isolated spots which might have been caused by a variety of particular circumstances, but also to know the average diminution over a larger area.

Initially it was hoped that two separate but related problems could be investigated. The one was the diminution in scantlings in tanks in which the steel work was not protected in any way. The other was to assess diminution, if any, in tankers protected by coatings or other means. In the first it was felt that if the rate of corrosion for particular cargoes over particular trade routes were established, then owners would be in a position to assess exactly the additional thickness of steel which they should include above the minimum renewal sizes required by the Classification Societies to enable them to operate without extensive renewals for a predetermined number of years. In this way it was hoped they would avoid costly delays at inopportune times. The second was to establish the rate of corrosion, if any, in structures protected by coatings or other approved means with a view to collecting data to present to the Classification Societies and regulatory bodies to enable them to agree to a reduction in so-called corrosion allowance included in their rule scantlings for new ships.

In addition to the coatings applied to the structure of the *Yukon*, mentioned by the Author, 11 existing T2 tankers and two existing T1 tankers had their tanks (or parts of them) and interior structure coated with protective substances, after having first brought the structure up to minimum classification requirements. In the ensuing eight years no extensive renewals of structure were required in these vessels.

In due course the data obtained by the A.P.I. Committee was submitted to the Classification Societies and in December, 1961, the Technical Committee of Lloyd's Register agreed to reductions in scantlings in protected vessels. These were incorporated in Notice 1 to the Society's Rules of 1962.

So far as I know, Lloyd's Register was the first Classification Society to grant reductions in scantlings in tankers protected against corrosion by approved means and our progressive approach in doing so was widely acclaimed in the Western Hemisphere, and also I believe in the Orient. Subsequently other Classification Societies followed us in granting similar scantling reductions in protected tankers.

By the end of 1964 the A.P.I. considered that the Tanker Corrosion Research Project had served its purpose and therefore it was discontinued, and the co-ordinator retired. Since that time corrosion research by the A.P.I. has continued as one of the normal functions of the Institute with a view to presenting data which would enable further reduction in scantlings to be made, especially in the chief parts of the main hull girder.

Those interested in a more detailed study of the history of this subject in the U.S.A. are referred to the American Petroleum Institute report of 10th November, 1964, a copy of which may be found in the London office.

Mr. H. P. URWIN

Mr. Clemmetsen is to be congratulated in producing a most excellent and absorbing and complete paper on Corrosion Control. He suggests that outport Surveyors may comment from personal experience just how successful these methods of corrosion control are.

Quite rightly, before dealing with methods of reducing corrosion the Author points out where corrosion is likely to occur in cargo oil tanks and here outport Surveyors can corroborate his statements.

In ships carrying spirit the deterioration of the steel due to corrosion is found mainly on the deckheads and 5 ft. below the top of the tanks. Deck longitudinals and the top 12 in. of transverses and bulkheads are nearly always found to have gone when we carry out the twelve-year survey, and in some cases the eight-year survey. I am, of course, referring to ships which have not been shot blasted or coated with epoxy coatings. I believe there is always an air space at the top of the cargo tanks which may account for the excessive corrosion of these parts, together with heat in those vessels trading in the Middle East. It is often found that the deck longitudinals corrode through just below the weld attachment to the deck: in fact, there have been cases where the longitudinals had parted company from the deck. This might be attributed to electro-chemical corrosion due to scale being left on or not properly cleaned off the welding. Scallops in the deck longitudinals are also subject to thinning, but this may be erosion as much as corrosion. It is now becoming the practice for older tankers in service to be shot blasted and epoxy resin coated for a distance of 5–6 ft. below the deckhead.

Tanks used for both oil and ballast have the worst cases of corrosion, particularly No. 1 tank (forward) which is always used as a ballast tank when the ship is in the ballast condition.

In black oil tankers carrying crude oil the outside Surveyor looks for pitting on the bottom of the tank and on flat surfaces in addition to deckhead corrosion. My firm belief is that this is due to formation of sulphuric acid as stated by the Author, particularly in ships carrying Kuwait crude and is due to cleaning out by the Butterworth system leaving pools lying against the transverses or trapped between the transverses. This pitting has been found particularly vicious when ships have had an excessive amount of cleaning by hot "Butterworthing". The above confirms the Author's pattern of corrosion in oil tanks.

The Author shows a considerable knowledge of protective coatings and wonders how successful these may be. From a limited experience it is believed these may prove very successful but I doubt whether, as yet, ships so dealt with are old enough to prove this.

Mr. J. M. Murray in 1952, only some 12 years ago, wrote in his paper on "Marine Corrosion"—"reliance on weathering, therefore, is bound to give variable results and if pickling is not practicable, then consideration should be given to the use of flame descaling; sand or grit blasting are not as yet applied to new construction". Only in recent years have tanker owners specified new construction tanker material to be shot blasted, primed and subsequently epoxy resin coated. We have had tankers doing their first survey which had been coated during new construction and very satisfactory results have been obtained, but on the other hand, rarely do we expect renewals at the first survey. We have had other cases of old ships where certain tanks, some time after building, have been been shot blasted or flame scaled and coated and at subsequent docking surveys we have found the coating peeling off.

It cannot be emphasised too much the importance of preparing the plates. I believe flame scaling to be no good at all and generally this practice has been abandoned. The larger building yards with properly equipped shot blasting and priming plants, subsequent wire brushing and cleaning on the berth and coating with epoxy resin paints can give an excellent finish which could stand in good stead at the eight-year survey when previously we started to find renewals. Zinc silicate coatings are extremely good but in the new construction yards zinc primers have caused trade union troubles owing to the stated fumes during welding. Several ships have been examined in Newcastle to ascertain how protective coatings are standing up and have all generally shown excellent results, except at the edges of hatches and Butterworth openings, the latter presumably due to mechanical damage, and edges of face flats, etc., where there has been lack of adhesion and local stress points such as ends of brackets.

Mr. Clemmetsen fully details cathodic protection by magnesium, zinc and aluminium anodes, the former having gone out of favour due to spark hazards. All have played their part in curtailing corrosion, but I think epoxy resin or zinc silicate paints will give the most satisfactory results if properly applied to clean surfaces. It cannot be emphasised sufficiently the importance of good preparation before painting. Three examples are given here:—

Tanker (A)

When the ship was five years old two tanks were mechanically chipped and epi-coated with paint supplied by eight manufacturers. In one year there was a complete breakdown of all paint.

Tanker (B)

This was a new ship where plates were weathered only, power wire brushed and tanks coated (four coats) with epoxy resin supplied by ten manufacturers. At the first survey in January, 1965, when exactly five years old, excessive breakdown of the coatings was found, possibly requiring shortly a full shot blasting and painting treatment.

Tanker (C)

This ship at eight years old was fully shot blasted and four coats of epoxy resin applied using two grades of paint in different tanks. After five years in service only one-half of one per cent breakdown was found, mainly on the tie beams where in way of staging the shot blasting had not been carried out efficiently.

It is also important to obtain the correct thickness of paint. In shot blasted plates on new construction, to obtain an uneven surface for keying the paint, the profile of the plate should be in the region of 3/1000 in. and paint thickness in the region of 7-8 mil. If blasting old ships, say five years old, the profile of the plates varies up to 18/1000 in. The paint runs into the valleys and off the peaks and surface tension on the peaks causes breakdown if only 7-8 mil. is applied. On old ships it is necessary to apply 14 mil. thickness of paint.

Cathodic Protection

Ten years ago one major oil company started fitting magnesium anodes in black and white oil ships. These were found satisfactory in black oil ships but not in white oil ships. The reason why they were not satisfactory in white oil ships was that the tanks required ten days filled with clean ballast before polarisation of the steel took place and this in service was not practicable. It could have been possible to fit large enough anodes to polarise in three days but the expense would have been prohibitive. Anodes are not now fitted in white oil ships in this company. Also, aluminium or zinc anodes are stated to contaminate white oil cargoes, particularly aviation spirits and petrol.

Black oil ships in this company are now fitted with zinc anodes because of the spark hazard of magnesium anodes. The results up to date have not been found too convincing as pittings in the bottom are still being found, stated to be because of the oil film forming on the anodes, as zinc does not throw the oil off as easily as did magnesium.

It is believed that the future policy of this company for new construction will be:—

(a) White oil ships fully coated.

(b) Black oil ships, deckheads and 6 ft. down, bottom and flat surfaces of stringers, etc., coated, with the addition of the inert gas system in the tanks.

In a 16,000 tons deadweight tanker, white or black oil, shot blasting and fully coating will cost approximately £60,000. In a 70,000 tons deadweight tanker, the cost of blasting and coating would be in the region of approximately £200,000. A shipowner can do a considerable amount of renewals for £200,000 at an eight- and twelve-year survey and oil companies may have to balance up these costs as to whether coatings are going to prove worthwhile. Certainly the advantages of coating white oil ships are: quicker gas freeing, quicker cleaning and draining. For large tankers of 70,000 tons deadweight

and upwards one company has stated that there appears to be an advantage in fully coating white oil ships but not an advantage in fully coating black oil in view of the costs. Estimates are on the basis of running a ship for 15 years and then scrapping it.

Mr. Clemmetsen queries whether these methods of corrosion control ease the burdens of outside Surveyors at survey work and will the frequency of Special Surveys be reduced? Tanks are certainly cleaner, but they still have to be examined, and with owners taking advantage of reduction of scantlings, I think it would be unwise in the meantime to reduce the frequency of special surveys.

Mr. P. H. VAN DER WEEL

The Author is to be congratulated on the comprehensive way in which he has been dealing with a matter that merits every Surveyor's attention, because of its present—and future—importance.

As regards the future, it will be interesting to know what will be decided by tanker owners once the costly "corrosion control" system obtained by surface preparation followed by the expert application of special coatings, has lost its efficiency.

Paint manufacturers have become more confident as time has passed by and experience augmented and to-day it seems reasonable to estimate the duration of efficiency of the good and well applied coatings at ten to perhaps twelve years.

Will tanker owners then: —

(1) Dispose of the ship?

(2) Start again on corrosion control by means of scaffolding, removal, surface preparation and coating?

(3) Change over to the apparently less efficient cathodic system? or

(4) Leave the steelwork unprotected?

The Surveyor will have to adapt his method of interpretation and judgment to the prevailing conditions of a more or less or no longer efficient system of corrosion control.

How will owners react to a requirement for costly stages underneath the deck?

How will the Surveyor recognise decay of the corrosion control paint system? How will he set about this?

I could well imagine that the inspection will be held from a raft floating on the surface of ballast water in the cargo tank, with the water level falling in the measure that the Surveyor is carrying out his inspection of the (brilliant) appearance (light green or "pailleté-gray") or otherwise of the well illuminated surfaces, hose-cleaned as necessary.

What will he be looking for? Signs of transfusion or of diffusion of gases, blisters, or small points of rusty colour, or patches, or the paint coming off the steel surfaces, or changes in colour of the paint coating?

Will the Surveyor be looking for signs of recent patching up and with what kind of paint?

It is hoped colleagues will communicate their experience in this line, if already available.

In case the owners decide to leave the steel structure unprotected, the Surveyor will have to consider the reduced future chances of the steel components. What will be the rate of deterioration in the next four years—or should it be five? If the thicknesses are just so-so, they may be decidedly below the minimum long before the next Special Survey.

Such tanker will then, in fact, embark on a second and different period of its life, on what might be called the tanker's "short life".

Owners' decision will have to find expression in the ship's class notation, and reference to it in the Register Book. We may then have to revert to the ancient system of class notation of less than 100A1, a comment already made by the C.S.S. in connection with a recent proposal to approve tankers built to reduced scantlings (5 and 10 per cent reduction) and having at the outset no "corrosion control" system.

Under "Corrosion Allowances" the Author refers to the proportional role assigned to the deck longitudinals in computing the total topside area.

The existing guidance notes on permissible reductions of tanker deck plating, based on percentages of thickness according to type of tanker and year of build seem no longer adequate. They are based on the assumption that the deck longitudinals are sound, which is rarely the case.

Years ago the sectional area of deck longitudinals was thought to contribute 40 per cent of the total topside area, but this percentage had to be raised as experience warranted and on practical consideration because tankers rapidly became bigger and bigger and there was a limit to the thickness of plating.

I think we are now at the stage where deck longitudinals and plating are equal in area and it seems therefore safe to use the area of existing deck longitudinals to the full in ascertaining the actual I/Y (deck), which remains to be compared with the original requirement, modified as necessary for date of build.

A new edition of guidance notes on acceptable reduction in tankers will be welcomed.

Mr. D. GRAY

Regarding cathodic protection for external corrosion it is probable that the wetted areas can be protected with currents of about 3 mA/ft.^{2} of painted hull surface. Higher current densities are required at stern areas and the propeller, which is not painted and is often bronze, may have a current demand up to 100 mA/ft.^{2}.

Thus a ship with 20,000 sq. ft. of wetted area may require an installation of about 200 A capacity.

The current required may be derived from reactive anodes or from a low voltage d.c. source. Points of comparison between the two systems are: —

Reactive Anodes

No attention necessary between dockings.

Lower installation cost.

No perforation of the hull.

Added drag due to fitting of multiple external anodes.

Impressed Current System

Skilled attention is desirable.

Current can be adjusted to meet the circumstances.

Frequent anode replacement is not required.

Lower operating cost.

Less added weight and little drag.

It is often preferable to use reactive anodes on smaller and/or slower ships. Larger and faster ships justify the cost of the more sophisticated impressed current system.

A deciding factor can be the effect of drag which may be caused by the fitting of large numbers of reactive anodes. Magnesium anodes are worse than zinc anodes in this respect since they require to be of larger cross section.

The drag effect will be greatest where a large number of bulky anodes are fitted spaced widely apart, the importance increasing with the service speed of the ship. An increase in hull resistance will result in an increased requirement for s.h.p. to maintain a given speed, thus increasing fuel consumption.

One full-scale test on an 18,000 tons deadweight oil tanker fitted with 48 zinc anodes each 24 in. $\times$ 12 in. $\times$ $2\frac{3}{8}$ in. resulted in an increase in s.h.p. requirement of the order of one per cent to maintain a service speed of $14\frac{1}{2}$ knots. However, there appears to be a complete lack of evidence, from other sources, from either full-scale or model tests on which to base general recommendations. One must, of course, set against this increased drag the reduced roughening which is to be expected on a cathodically protected hull.

Impressed current anodes should produce negligible drag.

It is interesting to note the Author's comments on the relative cost of tank coatings versus cathodic protection. To the best of my knowledge, most tanker operators in the U.S.A. prefer to use coatings rather than the apparently cheaper cathodic protection. Could the Author comment on this choice?

Mr. T. A. Blagburn

I congratulate the Author on a very comprehensive paper.

The Author seems to have covered all the salient points, which makes it rather difficult to comment, other than in a general way from the outside Surveyor's point of view.

Tank Coatings

"How far must the outside Surveyor concern himself with the inspection and checking of the coatings applied?"

To a certain extent we are "in the hands of the Philistines". The paint manufacturers are in control of the quality of their product and the claims they make for it, the preparation of surfaces and the application of the coatings are in the hands of the shipbuilders or more likely a sub-contractor, the owners usually select the coatings to be supplied and where Corrosion Control allowances are claimed the Society approves the system.

On a tanker of 53,000 tons deadweight—"C.C. with defined ballasting" I spent many hours in checking and inspecting tanks for "Corrosion Control". This job was done *in situ*, sand blasted, and two coats of tar-based epoxy applied, one thin primer and one finishing coat, both black. The inexperience of all concerned and the inadequacy of the sub-contractors' equipment at that time, plus the humidity, all contributed to the difficulties.

The sand-blasting produced a very good surface for painting but there were several tanks which had to be re-prepared due to delay in applying the first coat. It is essential that the coating be applied as soon as possible after blasting. Sand-blasting brings its own problems and the removal of the sand is a major one since unless all traces of sand are removed the coatings suffer. With regard to conditions of applying coatings in tanks of ships afloat or on stocks, dry and hot air can be introduced to reduce the humidity and maintain a reasonable temperature in the tanks, but this must be watched carefully and maintained for a reasonable period after the application of the coating. In this connection it was found that the staging planks in the tanks had absorbed and retained a great deal of moisture from the time of tank testing and gave off dampness which was difficult to overcome. It is suggested that tanks intended for coating should be tested only with air before coating, with a water test for structural purposes on completion.

The application of paint by spray is hardly an exact science and I agree wholeheartedly with the Author, that where two or more coats are to be applied each should be of a different colour. With the black tar coatings I found on several occasions comparatively large areas where the second coat was missing entirely.

The Author makes a very important point with regard to the construction of ships intended for internal coating for corrosion control. I think it is clear that in future all tankers will be coated internally as a normal part of a new building and it behoves the shipbuilders to produce designs which lend themselves to a good painting job. There are many parts of internal structure in present designs which are virtually inaccessible from the point of view of coverage by spray painting. I found, to ensure complete coverage, it was necessary to coat all scallops, overlaps at brackets and corners by hand brushing. This method, however, is not economical in either time or money and certainly not looked on favourably by anyone on contract at so much per square metre.

With regard to gauges for checking thicknesses of coatings, I would recommend the "pencil" gauge as described by the Author as being the most useful. It can be used in any position and has the distinct advantage that it only needs one hand to use it, which on staging is very important.

One advantage of the *in situ* job is that the tanks can be completed and properly tested before coating which, from the Surveyors' point of view, is very comforting when one thinks of the occasions when cracks have been observed in welds or plating when under test and which might not show when tanks are coated before testing. In this connection I feel that where tank structures are to be completely coated in shops before erection and testing on the stocks, all main welds, butts and seams of shell and deck plating and on adjacent parent metal should be examined ultra-sonically, with check radiographs as required by the Surveyor. Welding, automatic and manual is of a very high standard nowadays, but cracks and faults for one reason or another do occur in welds and material and we should always maintain some form of positive inspection to minimise the possibility of major structural failure later on.

There is little doubt regarding the advantages of tank coatings in respect of Special Surveys. The tanks can be easily and properly cleaned and in particular with light coloured coatings, defects can be spotted without much difficulty. The erection of staging need only be required to investigate suspect areas. Probably the greatest advantage gained is in way of the bottom plating where so many headaches have been caused due to "pitting". The coating of tanks will end the continued battle to get tank bottoms clean enough for examination and then deciding what to do with the "pitting" in the face of a sometimes resisting Superintendent.

On two Finnish tankers partly surveyed by the writer, the tank coatings "Epoxy" (five coats) were found in very good condition after four years. Some touching up had been done, but only in small areas.

The question of hull damage repairs in way of coated tanks is now very important to Underwriters where several more

days in dry dock may be required, plus the additional cost of recoating and while time and cost is not the prime concern of the Classification Surveyors, I think it would be well to remember this when making recommendations for repairs.

It would appear from information received that tank coatings are not always successful and in this connection, as a matter of interest, Figs. 1 and 2 provided by the local shipyard show failure of tank coatings after a period of eight months.

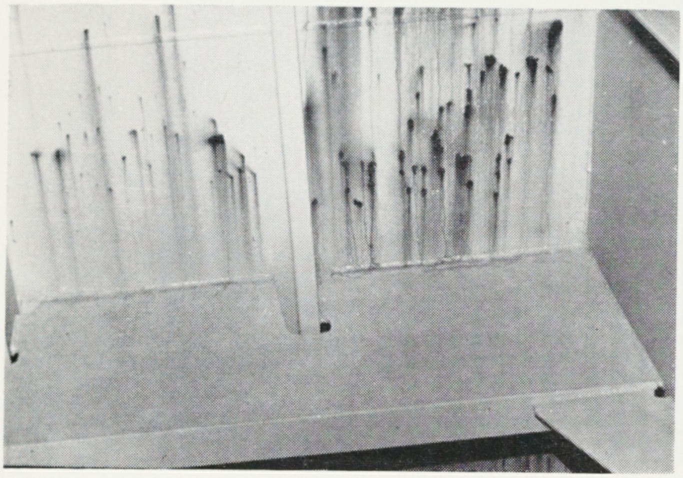


FIG. 1
Paint breakdown after eight months in service.
(By courtesy Kieler Howaldtswerke, Kiel)

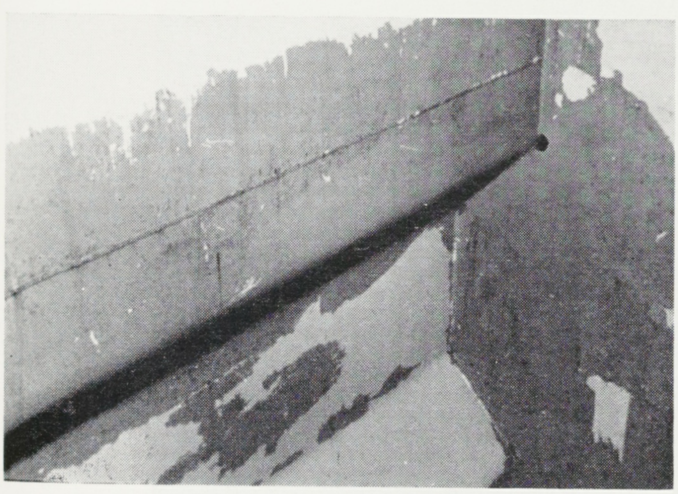


FIG. 2
Paint breakdown after eight months in service.
(By courtesy Kieler Howaldtswerke, Kiel)

The cause of failure in this case was stated to be porosity or, as mentioned by the Author, to "peaks" caused by rough surface preparation. The tanks were coated with four coats of "Epoxy" (6 mils).

In one further case, on a small tanker the four coats of "Epoxy" had completely broken down and shrunk after only a few weeks and could be removed like wallpaper, leaving only the primer. In this case the fault appeared to be that the first coat of "Epoxy" had not bonded to the primer, which had been applied at the steel mills, then locally prepared in way of welds and damaged surfaces *in situ*.

Reverting to applying tank coatings *in situ*, Figs. 3 and 4 show the tank coating equipment installed on the deck of a new building at present under construction in our district. The equipment includes sand driers, air compressors, air receivers and heaters, vent trunking, etc. The normal progress of the ship building is retarded and the ever present sand and dust is a continued source of complaint.

Welding on Shop Primers

In general, welding on approved shop primers is satisfactory, but this does not apply, in my experience, with the double continuous automatic fillet welding. The leading fillet can be completely satisfactory as the gases can escape, but this is not so with the trailing weld where the gases are trapped, with resultant porosity. Regular tests in our district have shown that this disturbing feature has not been completely overcome.

Welding on shop primers should always be treated with caution and regular checking in the shipyard should be made to ensure the necessary standard of the welding is maintained.

Mr. J. H. BLYTH

Comment has been made that the Surveyor, in addition to his numerous various duties, must now undertake the role of the painter's foreman. There can be no doubt, however, that strict attention must be paid to the application and service performance of the different forms of corrosion control if the Society is to be in a capable position to allow important scantling reductions and to provide sound advice to the shipowner.

As this very comprehensive paper shows, there has been in the last few years a tremendous advancement in the science and techniques of corrosion control, the various systems being offered to the shipowner at prices which can in some cases, approach or even exceed, the anticipated cost of normal renewals at a twelve-year Special Survey.

The perfect corrosion prevention still remains to be discovered and there can be no doubt that the one concrete guarantee, that is, the percentage scantling reduction, has been a great inducement for many owners to introduce an approved system of corrosion control. In addition to this reduction with the subsequent decrease in steel and increased carrying capacity, the owner is still seeking the protection which will have the longest service resistance to the effects of abrasion and corrosion, without the necessity of frequent renewals as is the case with cathodic anode protection or re-coating which is often necessary with the softer epoxy paints.

It would therefore appear that the inorganic zinc silicate type coatings with their excellent abrasive-resistant qualities have the most to offer in this respect.

Surface Preparation and Coating

The remarks regarding coatings being applied before or after fabrication are of no minor importance and there can be no doubt that the most efficient and economical practice is to complete the fabrication of each section prior to blasting and coating. Although the initial outlay will be expensive, subsequent overheads can be reduced to a minimum. This practice ensures clean welding, also scantlings and workmanship

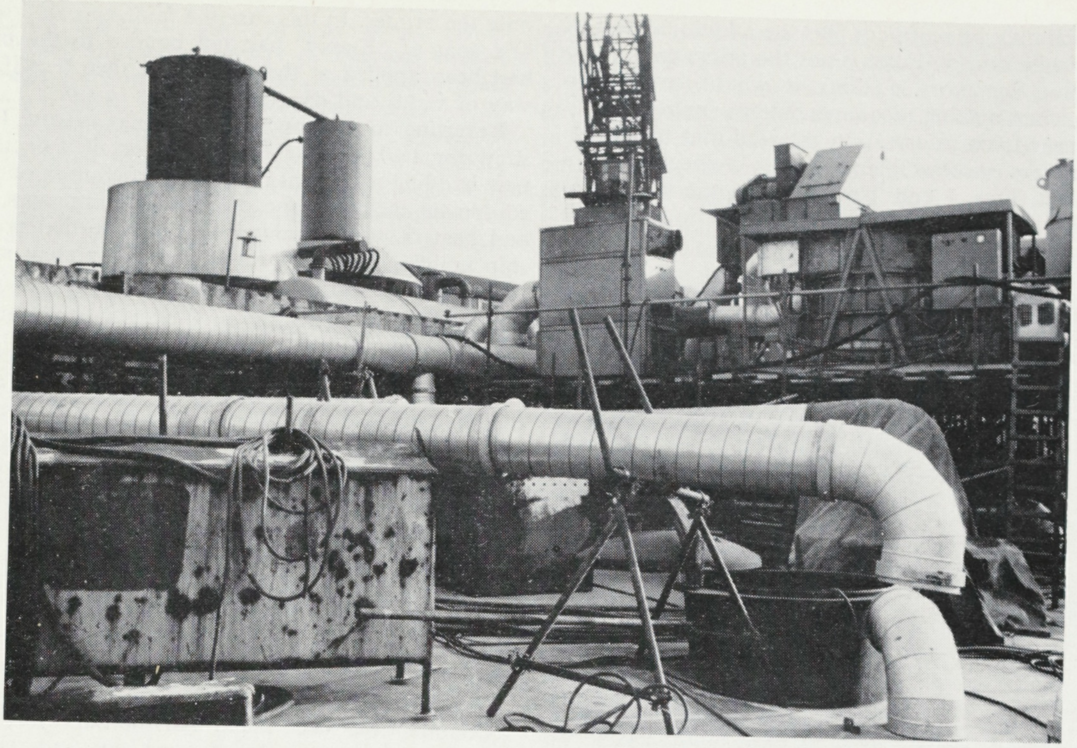


Fig. 3
Air drying equipment, etc., on deck of new tanker.
(By courtesy Kieler Howaldtswerke, Kiel)

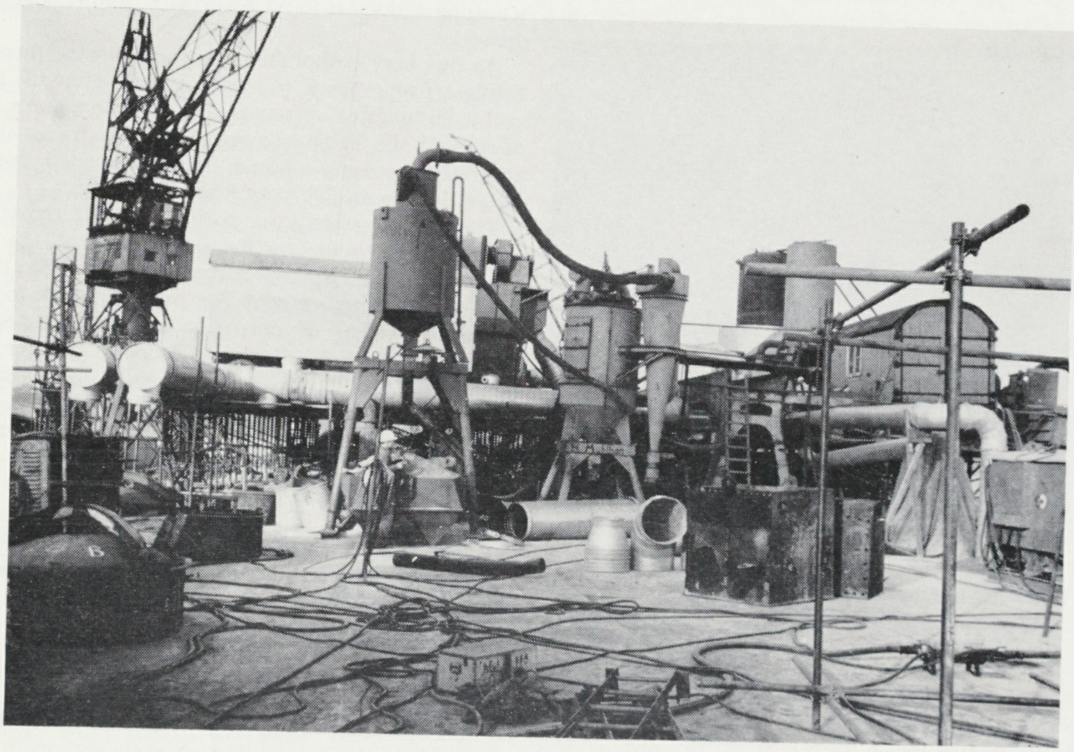


Fig. 4
Air drying equipment on deck of new tanker.
(By courtesy Kieler Howaldtswerke, Kiel)

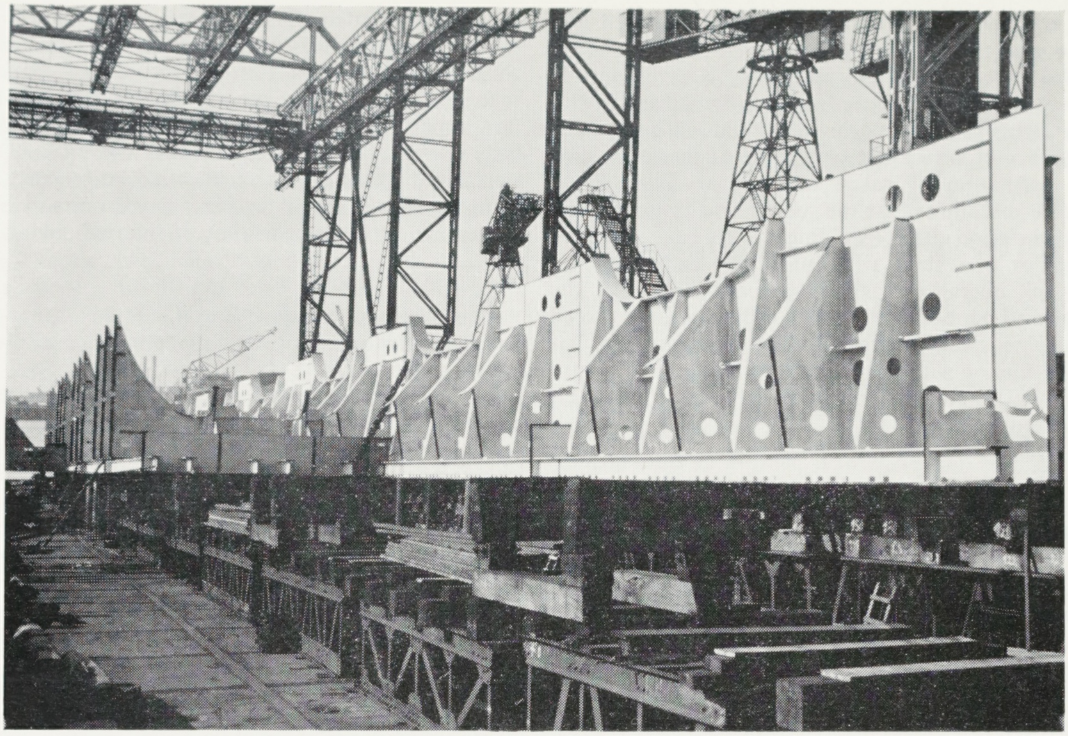


FIG. 5
Precoated prefabricated sections.
(By courtesy A.G. "Weser", Bremen)

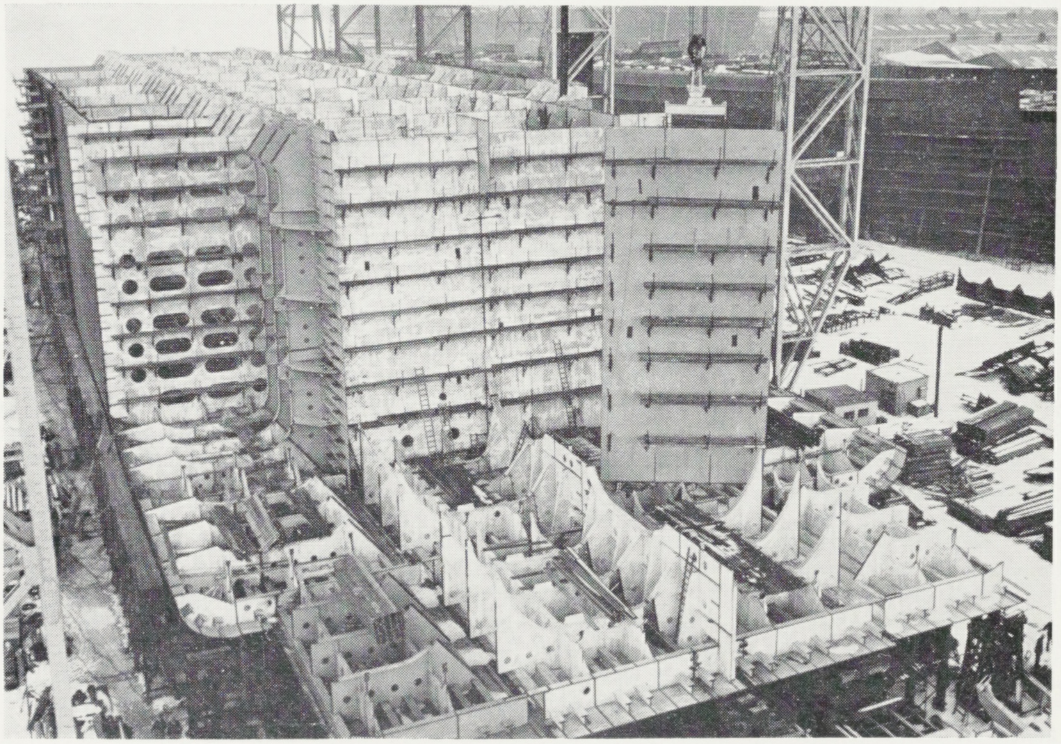


FIG. 6
Precoated steelwork.
(By courtesy A.G. "Weser", Bremen)

can be easily checked prior to the section being coated and shipped as a complete unit on the berth (*see* Figs. 5 and 6). This method leaves only the main section butts and seams to be welded on board and these edges can be covered with adhesive paper strips prior to coating, thus eliminating foreign inclusion in these very important welds and at the same time excluding the formation of gases, which apart from being unpleasant create discomfort for the welder and thus promote the tendency to inferior quality welding.

A further major advantage with the above system is that the "touching-up" operation carried out on board, with the added humidity and temperature control difficulties, is reduced to a minimum. This is very important when one considers that on a 90,000 ton tanker with complete tank coating there are approximately 180,000 running feet of main section butts and seams to be coated.

Paint Application

With reference to the inorganic zinc silicate type coatings, it can be confirmed that the main source of breakdown occurs in the vicinity of oversprayed areas, particularly at the corners formed by the welded connections of longitudinal and transverse members to flat plane areas. This defect shows up in the form of so-called "mud cracks", which are often microscopic in dimension and a Surveyor carrying out a tank survey on such a coating should not be misled by apparently perfect areas of intact coating.

The manufacturers' claim that this and other forms of breakdown in the coating can be further protected by the anode-cathode reaction which takes place between protected and unprotected parts is appreciated, but we must not forget that these corners are also liable to concentrated attack in the form of corrosion grooving.

Another defect which we have found in the self-curing type of the above coating is improper curing which can easily be caused by maladjusted atomization control during the spraying operation. This breakdown is noticeable in the form of a colour alteration, the even grey of the sprayed coating gradually changing to a mottled light grey/dark grey pattern and although having apparent surface hardness, the coating can be removed by scraping.

Two valuable and necessary additions to the hand instruments detailed by the Author are a pocket magnifying glass and a penknife.

External Cathodic Protection

The value of external anode protection is more difficult to estimate as the outside shell is already coated with an anti-corrosive paint and there are many ships of 20 years and older with little or no apparent corrosion, whilst at the same time there are many ships of recent construction having advanced wastage and pittings. One is apt to think that if more consideration was given to proper application and protection from the elements during painting at the dry docking, much could be gained to achieve an improved corrosion protection.

I have had the opportunity to see the same tanker in dry-dock on four separate occasions which had heavy corrosion pittings on the bottom shell. A careful check on the depth and extent of the pittings had been previously recorded, and after fitting of external anodes on the bilge strakes the rate of corrosion was found to be greatly reduced.

The manufacturers' claim, that external anodes have no deleterious effect whatsoever on bottom paints is doubtful and it would be interesting to hear the Author's views on the effect of the anodic-cathodic reaction with the copper toxic content of the normal anti-fouling paint.

It is also noticed in practice that external cathodic protection appears to have no effect whatsoever on fouling and also little or no effect on the wind and water areas, where unfortunately the heaviest external corrosion occurs. We are therefore apparently much farther away from solving the exterior protection problem than that of internal surfaces.

Anode Attachment to Structure

The details given regarding the actual fitting of the anodes are indeed valuable to the Surveyor when approving preliminary arrangements.

The apparent previous practice of throwing the anodes into a tank and welding these in position when they landed(!) has fortunately been improved upon in the last few years, although at surveys one frequently encounters anodes which have been attached at points of main stress concentration.

It is stated that several tanker explosions have possibly been caused by detached anodes falling into the cargo tanks and one would consider that the introduction of a general requirement regarding the annual inspection of anodes, similar to the Norwegian Authority Requirements, would be of assistance in helping to eliminate this risk.

During dry docking surveys it is also prudent to check whether anodes have been fitted inside the sea inlet boxes as these have been known to break away from their fastenings and the remnants drawn up into the circulating pumps causing subsequent damage.

In conclusion I wish to express my appreciation for this worthy addition to the many Staff Association Papers which now form standards of reference for the Surveyors.

Mr. L. DOHM-HANSEN

I have read Mr. Clemmetsen's paper with great interest and find it very informative, but, as the Author says, the paper will not be complete until we have heard from our colleagues' experiences how successful the different systems of corrosion control have proved in practice. I am sorry to say I cannot contribute to the discussion on this very important point, but there are in the part concerning coatings a few points I should like to comment on, from personal experience gained on the construction of two small tankers of about 2,000 tons deadweight and 5,000 tons deadweight respectively.

On page eight the Author states that the epoxy-phenolic resins have the disadvantage of requiring a high temperature cure, and a figure of about 165° C. is mentioned. On the first tanker three cargo tanks intended for the carriage of caustic soda were coated with a paint stated by the manufacturer to be an epoxy-phenolic coating. All surfaces were prepared by sandblasting after the completion of the hull. The paint was applied in four coats, and each coat was allowed to dry at normal air temperature. The final curing was obtained by baking at a minimum temperature of 50° C., metal temperature measured on the outside of steel structures, for 48 hours. To obtain and maintain this temperature the deck and side shell concerned were insulated with glass fibre mats, and hot air was continuously circulated through the tanks. Additionally to this hot air supply, steam was led through the tanks' heating coils and coal fires were arranged underneath the bottom. After the baking the tanks were allowed to cool gradually. The curing was finally tested by placing pieces of

cloth soaked with a special thinner on top of the coating, and if, after about ten minutes, the surface remained hard and glossy the coating had cured properly. I have given a complete description of this very complicated curing process to explain why I very much doubt that the Author's figure of "about 165° C." is correct. Such a temperature does not seem to be realistic, at least not within shipbuilding, but perhaps this is more a matter for discussion between the manufacturers of epoxy-phenolic coatings. Whilst discussing disadvantages it might also be mentioned that this particular coating had a low flash point and did not resist mechanical damages.

The remainder of the tanks on the first tanker and all the cargo tanks on the second were coated with a single coat of an inorganic zinc silicate coating of the self-curing type, applied to the completed structures. Especially in the case of the latter ship, which was built during the winter time, the weather conditions caused some difficulties, and to ensure a proper cure, hot air, with a humidity of less than 50 per cent and giving an ambient temperature of about 15° C., had to be circulated through the tanks. But to arrive at the point. On page ten the Author says "Welding may take place on these coatings without deleterious effect" and in Amendment No. 1 to Part 2a in the Instructions to Surveyors, it says "Welding should not be carried out on epoxy-based or zinc silicate coatings . . .". In accordance with the manufacturers' instructions for the above zinc silicate coating welding may be allowed on this coating, but precautions have to be taken against the poisonous vapours then developed. I should be pleased to have the Author's comments on this point regarding welding.

Finally, to the Author's question if these systems are making subsequent survey work easier, I am of the opinion that the answer should be yes, but on the other hand, it is certain that the amount of survey work during the construction has increased.

Mr. S. KAMITANI

I would like to begin by expressing my gratitude to the Author for his paper on "Corrosion Control" which is a great help in understanding the mechanisms of corrosion and corrosion control which have been tried up to the present. The Author seems to have specially emphasised the electrochemical action in the corrosion mechanism and the use of coatings as the most favourable means of control. This appears to be the view most generally held with regard to tankers. He has also referred to and amplified cathodic protection, inert gas systems, oil and water soluble inhibitors and dehumidification as well as referring to changes in the Rules which leaves few opportunities for comment.

However, I would be much obliged if the Author could give further information on the following items which are not mentioned in the paper: —

1. Other patterns of corrosion and changes in the method of control.

Unfortunately, I do not have the previous L.R. paper by J. M. Murray in 1952/53 and I therefore do not know whether Mr. Murray described the mechanisms of corrosion with regard to "corrosion fatigue", "intergranular stress corrosion cracking" and "transcrystalline cracking". These types of corrosion may be controlled by improvement of design in both cargo ships and oil tankers. In cases where there is a stress concentration in a structural member and at the same time there is corrosion then we must improve the structural arrangement. In this connection, there must have been a lot of improvement in design and if the opportunity is given to see these historical changes it might be of great help in surveying new construction as well as in repairs.

I once read that in a particular instance the corrosion rate under fatigue conditions was reported to be 0·5 mm./year and this must be considered quite a serious figure.

2. Washing down with sodium nitritic or caustic soda solutions.

As described by the Author the washing procedure is necessary and this usually takes place at sea during the ballast voyage and is an important factor in corrosion. I have heard that washing down tanks with sodium nitritic or caustic soda solutions will reduce corrosion in tank structures in the empty condition after cleaning and that it seems to be good for preventing the structure from pitting and/or grooving. Unfortunately, I have no experience of this means of corrosion control and I wonder if the Author has any data on this subject.

3. Metal blasting—so-called "Metalicon".

Melted metal blasting (Metalicon) appears in some ways to locally control corrosion. Has anything been done with this method in ships? The system is considered to have the following merits: —

(a) The thickness of blasting can easily be controlled.
(b) Application is fairly quick.
(c) It can be applied anywhere.

However, there are also disadvantages: —

(a) Blasted metal consists of a fair amount of an oxidised substance and there is some lack of adhesion.
(b) It is not known how far Metalicon will prevent oxygen permeation.

In view of the above this method may not be satisfactory.

4. I wonder if there is any experience in using nickel chrome steel for the tank operation of small clean tankers. This steel is effective against corrosion and corrosion rates are about $\frac{1}{2}$–$\frac{1}{3}$ of mild steel in salt water.

5. Impressed current cathodic protection.

I have had experience in the installation of the above cathodic protection system on the external hull and it may be that it may be used in cargo oil tanks if the safety aspect could be improved. Is there any kind of impressed current system suitable for use in cargo oil tanks?

In the end, I have to come to the conclusion that tank coatings as mentioned by the Author are the only satisfactory means of corrosion control in spite of the expense and labour in preparation and the need for maintenance and periodical recoating.

Corrosion in tankers has always been a source of trouble to me when examining existing ships and I hope that in the very near future means will be found of controlling it.

Mr. W. B. SCHEELINGS

The Author has presented a paper covering the complete field of various types of corrosion control from commencement of building of the ship and during the time that she is commissioned.

The information given in detail will no doubt be very useful to many Surveyors for which the Author must be thanked.

The contents of the paper and the recent alterations to the Rules in this respect, which I learn have also recently been extended to include bulk carriers, raise some questions,

especially from outdoor Surveyors and a reply will no doubt clear a number of misunderstandings.

The Author points out that it is the owners responsibility to maintain the corrosion control system. May we understand from this that also the application of the corrosion control and eventual repair is the responsibility of builders, repairers/owners, respectively, and that it is not the intention that the outdoor Surveyors check curing and thickness of coatings, quality of anodes, etc. It must be understood that checking of coatings for instance is a very laborious and time devouring job.

Is the Author of the opinion that not only the corrosion control system must be approved but also the firm who must apply the coatings, as success depends not only on the coating but also on the conditions under which they are applied and these require special equipment, temperature and humidity control?

The Author also prescribes tests required for approval of shop primers with a view to welding on these primers. In nearly all yards—and in the very near future also by mills—shop primers are being applied immediately after the plates and sections have been shot blasted. After that, the marking off is carried out and plates cut to size, and provided with the appropriate bevel. During cutting, the edge of the plate is again bare metal and no primer is being applied before welding.

Fillet welds for attachment of stiffeners, etc., are being made on top of the primer, and as mentioned, the primer can affect (mostly porosity) the quality of the fillet weld.

Is the Author not of the opinion (with a view to the above) that the requirements 1–4 must be revised and more attention be paid to tests on fillet welds, especially on double continuous automatic fillet welds?

The Author mentions further that the use of magnesium anodes has been banned. Does it mean that when, during surveys, it is observed that the cathodic protection is maintained by magnesium anodes that it must be replaced by another method?

Furthermore, is he of the opinion that the combination, magnesium anodes together with an inert gas system, can open a new field for the magnesium anode? Can he state whether this combination has been investigated?

MR. S. A. D. SCHIERWAGEN

There are one or two points mentioned in Mr. Clemmetsen's very instructive paper, on which I would like to have some further information. No mention has been made regarding the difficulties which can be encountered during practical work with shot blasting of welds, especially of hand welds made in the upside-down and vertical positions, prior to the application of protective coatings. Welds such as these, particularly if they are fillet welds, often have a very rough surface, which must be difficult to clean from slag with the medium-sized shot or grit otherwise desirable from the anchor-pattern point of view. Porosity in welds, undercutting, weld spatter, as well as improperly removed tack welds also present a problem in connection with blast cleaning. How does the particle type, size, specific gravity, etc., affect the cleaning of welds such as the ones mentioned above?

A paint manufacturer, who specialises in marine protective coatings, recommends that all rough welds should be ground smooth and all weld spatter be removed before blasting. As grinding of welds is a very tedious and expensive procedure, it seems rather unrealistic, and I would appreciate to have Mr. Clemmetsen's comments on this point. A more realistic solution might be to increase the use of basic coated electrodes, as these give a smoother surface in the vertical and upside-down positions and also cause less weld spatter.

AUTHOR'S REPLY

The Author would like to thank all those who have contributed to the discussion on this paper, especially as the information given being largely factual, it does not lend itself to many questions. By giving us the benefit of their personal experiences, the contributors have added a great deal to the value of the paper. Before going on to answer the various points which have been raised, I would like to draw attention to one or two errors which have come to light since the paper was printed.

In the third paragraph of page 4, it is necessary to emphasise that the owner's permission for the adoption of reduced scantlings was only necessary initially and this no longer applies.

On page 4, 2nd column, 8th line from bottom, "C" should be "C_b".

On page 13, 2nd column, 3rd paragraph, "Ag/AcC" should be "Ag/AgC1".

On page 8 under "Epoxy Resin Coatings", special mention has been made of the possible effects on epoxy paints of prolonged exposure to fresh water. This note was inserted at a late stage in the preparation of the paper due to a recent failure. There does, however, seem to be a divergence of technical opinion on this point as one manufacturer has warned of the dangers, yet others are fully prepared to back their products in fresh water. Apparently, good resistance can be obtained for some time followed by rapid failure. Such failure can be due to pinholes and voids created by leaching out, or evaporation of residual solvents. In fact, the failure mentioned above has since been attributed to solvent retention between the coatings, i.e. to incomplete cure. Special attention to proper cure between successive coats has been mentioned in the paper. It is difficult to verify whether a coating is completely cured but research is going on to find suitable methods. An experienced operator can determine the extent of the cure by the degree of softening which takes place when a pad of cotton wool, impregnated with methyl isobutyl ketone is placed in contact with the coating for one hour. There is also an electrically heated element with a special head which gives a varying number of impressions in the surface of the coating as a measure of cure, but this instrument is not at an advanced stage of development.

No mention has been made of paints which can be used in ballast-only tanks, but one coat of bitumastic solution applied to blast cleaned surfaces, followed by one coat of bitumastic enamel applied hot, at 8 mils total thickness, have been accepted for this purpose.

On page 16, the anode output is determined when the anode has been consumed *by* (not "to") 40 per cent of its original

volume, i.e. half-way between its original volume and 20 per cent of its volume, and the life is determined by dividing the current capacity multiplied by the number of hours in the year *and* the anode output. The anode output is usually taken to be the output in the polarised condition.

It is also thought advisable to draw attention to the fact that in the cathodic protection part of the paper, the term "low potential" has been used as referring to the actual potential of the anode material, but, in practice, anode manufacturers often refer to zinc and aluminium anodes as being low potential anodes and they are then referring to the low driving potential of these materials relative to steel.

Mr. Roberts has given us more of the background to the reductions of scantlings given in the Rules, and has shown that the Society has been deeply interested in this field for many years.

Regarding the rate of diminution of plating in tankers, a paper given by P. Talma of Shell Tankers, N.V., to the Congress accompanying the Europort 1964 Exhibition in Rotterdam gives some interesting results for the Shell 18,000-ton tankers which I give below. In the paper the results are given in percentages but I have also converted them to inches. The figures are for a period of eight years, of which three years were on white oils and the remainder on black oils. The centre tanks were used for cargo ballast and were cathodically protected while the wing tanks were used for cargo only.

24 mm. deck plating—
centre tanks 6% (0·06 in.) wing tanks 11% (0·10 in.)

11 mm. deck longitudinals—
centre tanks 25% (0·11 in.) wing tanks 32% (0·14 in.)

18 mm. shell plating— wing tanks 7% (0·05 in.)

11 mm. bulkhead girders—
upper centre 14% (0·06 in.) upper wing 23·5% (0·10 in.)
middle centre 10% (0·04 in.) middle wing 20·5% (0·09 in.)
lower centre 9% (0·04 in.) lower wing 20·9% (0·09 in.)

The advantages of cathodic protection show up on the stringers but it is apparent that it has had little effect on the deckhead.

The larger reduction in thickness of the deck longitudinals (two sides exposed) as compared with the deck plating (one side exposed) is apparent. As such results must represent a considerable amount of averaging of results from individual tanks, too much reliance should not be placed on the absolute values of the figures.

Mr. Urwin's experience with coatings on four tankers having various kinds and degrees of surface preparation is very interesting and I commend the principle of varying the paint thickness depending on whether new or old construction is being coated.

The remarks on cathodic protection are noted but so far as I have been able to ascertain, the preference for coatings instead of cathodic protection in white oil ships is due primarily to the cleanliness of the coated tanks resulting in easy cleaning, gas freeing, etc.

The area of exposed zinc or aluminium in a cathodically protected tank is insignificant compared with the quantity of oil in the tanks, although Government departments shipping aviation spirit may take a different view. Tanks which are completely coated with only a zinc rich epoxy coating which is gradually consumed in service could, however, alter the situation. Such coatings require to be covered with an epoxy amine or poliamide system when white oils are carried.

As stated by Mr. Urwin the chief problem to-day is that with crude oil cargoes the low potential anodes do not have the throw of the magnesium anodes and as they do not produce a reasonably thick calcareous film, polarisation cannot be maintained for those periods when the tanks are empty except for a small amount of water below the level of the bottom longitudinals. Pitting can then still continue on the bottom shell unless the anodes are placed low on the longitudinals. Due to the shielding effect of the longitudinals this layout probably involves more anodes.

Recent practice with aluminium and zinc anodes has ignored any beneficial protective effects from the waxy deposit from crude cargoes and the number of anodes corresponds to white oil standards on the horizontal surfaces on the basis that the anode output is restricted in proportion to the waxy deposit in the tank. This greatly increases the number of anodes each of which is called on only to protect a small area but the anodes last longer due to their lower output in these conditions. I think it is as well for Surveyors to observe whether or not anodes are being consumed if corrosion of the bottom is found to be continuing in the presence of anodes and to suggest re-location of the anodes at a lower level if necessary.

In spite of the unknowns accompanying the use of cathodic protection, it appears that where coatings are employed on a selective basis as in crude carriers it is being found prudent to provide a certain number of anodes to protect the steel in case of paint breakdown.

Mr. van der Weel has raised some very pertinent questions regarding the future of corrosion control systems but as reductions in scantlings, on account of corrosion control, are of comparatively recent origin one can only hazard a guess at the answers.

I agree that there will probably come a time in the life of the ship when it is no longer profitable for the owner to continue maintaining the corrosion control system but it is extremely difficult to say when this is likely to be. Coatings properly applied when the ship is new should last between eight and twelve years but even after this time it may be economical to reblast and repaint since this is what is now being done to existing ships of this age. There should not be any difficulty in giving adequate facilities for an inspection as the Rules require a drilling survey after 12 years whether or not a corrosion control system is fitted and the owners are hardly likely to raise objections to fitting the limited amount of staging which is probably necessary at intermediate surveys. If it is not economical to renew the coating then this may be because the ship itself is not economical to run and in these circumstances it would be scrapped. However, if the circumstances are such that the ship continues to operate and the corrosion control system is not renewed then the Surveyors will require to report this to the Committee who may find it necessary to draw attention to this fact in the Register Book, perhaps by putting a line through the CC notation and adding the date. The difficulty in altering the class of a ship as mentioned by Mr. van der Weel to, say, 90A1 in such cases, is that there may be older ships afloat with 100A1 class in which the scantlings have deteriorated below those of a ship in which the owners have only just decided not to maintain the corrosion control system. The Committee have in fact decided that the proposal to build short-life tankers with reduced scantlings but no corrosion control system cannot be approved.

Regarding paint breakdown, it is unlikely that a wholesale deterioration of all the coating will occur at the same time and the owner will therefore presumably keep the coating as intact as possible by repair with the same type of paint. As corrosion cannot take place below a coating without the latter being forced off, the signs of failure will be obvious and this is confirmed by Mr. Blagburn's contribution. Corrosion of horizontal surfaces where the paint has broken down in tanks which are selectively coated may be worse than is the case with completely protected steel, when crude cargoes are being carried, and the corroded parts should be obvious. If the tanks are completely coated as would be the case in a refined spirit carrier then corrosion of bare areas is not likely to be so severe. With cathodic protection it will be obvious from the state of the anodes whether they require renewal, but because anodes very rarely halt corrosion completely the Surveyors will require to keep a more careful watch on the structure in these cases for signs of excess reduction in scantlings. If the present practice for large ships to be engaged as crude carriers continues then the corrosion will be in the form of pitting and therefore more easy to detect.

As regards possible action by the Surveyor at a given special survey in expectation of deterioration below minimum requirements before the next special survey, it would appear that we are not in a worse position than we are to-day, except that the Surveyor will have to make his decisions on the basis of a known initial reduction in thickness. This initial reduction is not so large that the complete margin of strength will be lost in a period of five years especially in the case of internals.

I note the remarks regarding the permissible wear-down in tankers. In assessing the wear-down in the past it has been the practice to assume that the breakdown in the deck longitudinals is comparable with the deck wear-down. Although such wear-down is often exceeded in practice the deck longitudinals in these cases usually require renewal on the basis of local strength. No doubt revised guidance notes covering the allowable wear-down of the latest tankers and taking into account the greater relative importance of the longitudinals will be provided in due course. It might, however, be mentioned that deck longitudinals in general still account for not more than about 40 per cent of the total topside area.

Mr. Gray has provided further information on external cathodic protection, a subject which I only referred to briefly in the Appendix.

The bulkiness of magnesium anodes for external protection is due mainly to the fact that they are consumed more quickly than zinc or aluminium anodes as the more negative potential of the magnesium prevents it from being self-regulating.

The U.S.A. preference for coatings is probably due to the preponderance of refined spirit cargoes carried in that country. Such cargoes require clean tanks and this is not readily achieved using cathodic protection. As a result of the foregoing much more research work has been done on coatings in the U.S.A. than in the U.K. However, the contrary is the case as regards cathodic protection as no effective investigation into cathodic protection appears to have been done in any country until the Shell tanker experiments on the *Auris*, referred to on page 13 of the paper, and this gave a fillip to cathodic protection in this country. Cathodic protection is also in some ways more suited to crude cargoes commonly carried in U.K. ships as the anodes can be located in more accessible positions on horizontal surfaces whereas with a spirit cargo they would require to be distributed over all the structure.

Mr. Blagburn has given us an account of the difficulties encountered when blast cleaning *in situ* and the point regarding increase in humidity, eventually found to be due to wet staging planks, is certainly one which would be difficult to foresee. The latest Rules regarding tank testing should be found satisfactory for the application of coatings as they permit air pressure to be used on all tanks supplemented by a hydraulic test on individual tanks selected by the Surveyors. Most of the initial troubles with the paint application which he mentions, appear to be attributable to inexperience and no doubt they have now been overcome.

The preference for the pencil type of thickness gauge is noted and it may be mentioned that certain of the other types have been found to suffer from the disadvantage that they make an impression in a partly cured coating which results in a false reading in addition to the fact that a locally thin spot is produced.

The application of coatings before testing does mean that a heavier responsibility is placed on the builders and Surveyors to ensure that welding is satisfactory and complete before coating takes place. The question of whether inspection is made easier if the coating is applied at the fabricated section stage or whether it is easier when the structure is blast cleaned *in situ* is difficult to decide as each method has its advantages and disadvantages. If the hydraulic testing of specimen tanks only is adopted then even more emphasis will require to be placed on dry surveys.

An interesting point is raised by the question of damage repairs to coated areas. Underwriters may well require to take coatings into account when fixing premiums if the use of coatings increases.

Mr. Blagburn's remark regarding defects in coatings seems to answer Mr. Van der Weel's question on this point and shows that defects in coatings which have been in service for some time are easily observed.

Mr. J. Blyth has given much practicable advice regarding the application of coatings at the fabricated section stage and these require no further comment.

Regarding external cathodic protection it has been found necessary to surround impressed current anodes with an area of special coating which will be resistant to the alkalis formed by the cathodic reaction. Usually coal tar epoxy paints are applied for a distance of about six feet all round the anode and no ill effects are then observed on paint work. These precautions are not necessary with galvanic anodes of zinc or aluminium.

Cathodic protection is not intended to, and will not improve anti-fouling characteristics except in so far as it prevents corrosion, it then makes for a smoother hull. External anodes should not have any effect on anti-fouling paints since, to do so, the latter would have to form part of the same electrical circuit as the anodes. This circuit is only formed in places where the hull paint is scraped off to bare steel and normally the anti-fouling paint is insulated from the hull by the anti-corrosive paint system.

Mr. Blyth's remarks regarding wind and water areas underline the fact that for cathodic protection to be effective the structure must be immersed for a reasonable period and that this period will need to be greater for the outside than the inside of the ship since the ship is in motion.

Inspection of anodes is covered by the Rules at Special Surveys. To inspect the anodes at more frequent intervals would mean that the Surveyors would require to examine the appropriate tanks annually and this would be impracticable from the operators' viewpoint although the Society would commend owners who give instructions to their crews to carry out such an examination. The British Chamber of Shipping has recommended its members to inspect anode insulations, but so far only the Norwegian authorities have made the inspection mandatory, such inspection to be carried out either by the crew or by a Classification Society's Surveyor.

The method of effecting a cure of the epoxy-phenolic resin coatings on the tankers surveyed by **Mr. Dohm-Hansen** shows what can be achieved by improvisation. In these cases the tankers had to carry special chemicals, so this type of coating was a necessity. Regarding the question of curing temperature for epoxy-phenolic coatings, I checked my original source of information and the curing temperature of 165° C. given in the paper was confirmed. It was stated that the coating concerned must have been modified and some of the properties of the pure epoxy-phenolic resin sacrificed in order to effect a cure at 50° C., so it seems that this question is one which can only be decided by the paint manufacturer.

The Instructions to Surveyors referred to by Mr. Dohm-Hansen will require to be modified as many manufacturers have shown by tests that welding may take place on zinc rich epoxy primers and inorganic zinc silicates, although the advice given in the Instructions still applies to epoxy amine or poliamide coatings.

Mr. Murray mentioned various forms of corrosion in his 1952/53 Staff Association paper but dealt mainly with electrochemical corrosion. As the various forms of failure mentioned by **Mr. Kamitani** are associated with corrosion, if the latter is eliminated or minimised then the incidence of failure will also be reduced. It is agreed that proper attention to detail design will also reduce failures in a corrosive atmosphere and this is recognised in practice. It is impracticable in this reply to go over the various changes in detail ship design which have come about as a result of experience since the advent of the predominantly welded ship, but I can refer Mr. Kamitani to a recent publication of the Society with the title "Detail Design in Ships" which will assist him.

The practice of washing down with caustic soda or sodium nitritic solutions was primarily to assist in tank cleaning especially when changing from black to white oils. At the same time, when it removed the oil it eliminated the isolated pools of water lying beneath the oil film and thus reduced the incidence of pitting corrosion and in addition the alkali would neutralise any acids present. I understand that the use of the above solutions is now diminishing in favour of the newer chemical cleaning methods.

I am not familiar with the Metalicon process but conclude this is a metal spray. Zinc metal spraying has been used in steel yachts and also to considerable extent in trawlers, especially in the fish rooms of the latter where very corrosive conditions are met. It is essential for the surface to be thoroughly blast cleaned and it is customary for the zinc coating to be 8–10 mils thick. Thinner coatings have sometimes resulted in failure and in addition if applied to very thin plating the flexing of the plating has sometimes also caused failure. The latter has been corrected by using sharper blasting abrasives or by using intermediate bonding coats of carbon steel to increase the adhesion to the structure. Where aluminium is used it has been found that the coating must be sealed the same day to prevent penetration by moisture since it is a characteristic of aluminium that, although it is normally anodic to steel, it is temporarily cathodic when it is first applied. Aluminium vinyl paints are used for sealing in atmospheres which are exposed to salt water immersion.

Stainless steel has been used on chemical and wine carriers also in deep tanks of ships carrying special cargoes. The tanks are usually fitted as an integral part of the hull but separated from the outer shell by cofferdams, the latter being used as ballast tanks. Using this method of construction all stiffening (which may be of non-stainless material) is arranged on the outside of the tanks leaving a flush surface inside for ease of cleaning. Any internal divisional bulkheads can be of corrugated construction. Mild steel clad with stainless steel is also used for external bulkheads.

Regarding impressed current cathodic protection this does offer great possibilities for the internal protection of tanks but so far no system has been approved for use in cargo oil tanks.

Mr. Scheelings raises the question of responsibility for the proper application of the coatings. Although the Society requires to be informed of the type and thickness of coating being applied and of the maker's experience with it, the Society has always emphasised that the final responsibility for the choice of a particular coating lies with the builders and owners. Such being the case the final responsibility for the correct application of the coating must lie with these parties or their agents, i.e. the paint manufacturer and the painting contractor. Nevertheless, within this framework the Surveyor on new building can have a "watching brief" by noting in his journal and drawing the attention of those concerned to any irregularity he observes during his normal duties. In these duties I would include random checks of thickness during tank inspections, noting whether coatings are being applied in adverse circumstances such as wet or very cold weather and ensuring in association with the painting contractor that coatings have cured sufficiently to permit water testing.

As emphasised above, the foregoing remarks refer to new building. In the case of repair work full responsibility must be with the owner and repairers as the thickness of the coating to be applied very much depends on the condition of the existing plate surfaces after cleaning.

The question of satisfactory tests for welding on a shop primer is a difficult one. Although it is agreed that the present butt weld tests do not necessarily represent yard practice they do provide a large area of coated surface on which to weld and observe any adverse effects. Any test is only strictly valid for the electrodes with which the tests have been made (as is mentioned in the approval letter) and the tests are therefore only a guide to performance. Although troubles with automatic fillet welding and primers have received the occasional mention no widespread complaints have been received in Head Office. It can therefore only be concluded that either these problems are overcome in practice, or that any porosity found is no worse than would have been previously accepted when fillet welding on the type of lightly rusted surface that was common before blast cleaning and shop primers were in use and this porosity is therefore accepted.

Existing magnesium anodes must be replaced by anodes of zinc or aluminium only when the former require renewal. While there is no chance of a spark arising from a magnesium anode in an inerted atmosphere this safe atmosphere may not always be maintained in practice, e.g. accidents have occurred

when tank cleaning, and therefore no concession in the use of magnesium anodes has been made on this account.

Mr. Schierwagen should find no difficulty regarding the standard of weld finish with automatic welding and it should not be necessary to grind welds unless they are very rough. It must be recognised, however, that weld surfaces and weld spatter will inevitably be among the first areas of paint breakdown unless special attention is given to these areas by means of extra coats of paint unless the overall paint system is of sufficient thickness. I would consider the removal of weld spatter to be more important than the grinding of butt welds. The problem of rough welding will be less with the coal tar epoxys and high-build coatings, both of which are at least 8 mils thick per coat.

The efficiency of blast cleaning is so much influenced by air pressure, grit size and type, nozzle to steel distance and nozzle angle, etc., that it is not possible to give advice on the subject of cleaning weld surfaces, but as more and more fillet welding is done by machines, the magnitude of this problem should diminish. By careful arrangement of prefabricated sections, hand welding and overhead welding should be reduced as much as possible.

Printed by Lloyd's Register of Shipping at Garrett House, Manor Royal, Crawley, Sussex, England

Lloyd's Register Staff Association

Session 1964 - 65

Paper No. 6

GLASS REINFORCED PLASTIC BOAT BUILDING—PARTS V AND VI

by

A. McINNES

LLOYD'S REGISTER OF SHIPPING

71, Fenchurch Street, LONDON, E.C.3

The Author of this paper retains the right of subsequent publication, subject to the sanction of the Committee of Lloyd's Register of Shipping. Any opinions expressed and statements made in this paper and in the subsequent discussion are those of the individuals.

GLASS REINFORCED PLASTIC BOATBUILDING - PARTS V AND VI

by A. McInnes

PART 5—SURVEY AND INSPECTION

PART 6—REPAIR AND MAINTENANCE

5.1 SURVEY PROCEDURE—NEW YACHTS

5.1.1—General

Plastic inspection procedures in boatbuilding have been largely visual or non-destructive. Physical tests have been made, but generally on sample lay-ups which are seldom representative of actual hull laminates. Since strength tests on the finished laminate are impracticable, a close check must be kept during fabrication on moulding procedures and also on workshop conditions.

As it is impracticable for the Surveyor to be in constant attendance and with such short moulding cycles, a considerable amount of work can be done between the Surveyor's visits. Therefore, to avoid having to accept suspect or faulty work, the rectification of which would be of greater suspect, and avoid having to reject the complete hull, the various procedures prior to the operations being carried out should be discussed with the moulders. A check should be kept on the compliance with the approved drawings and specifications but as it is difficult to convey plastic matters on to drawings, this will also involve discussions with the moulders as to their intended construction methods.

5.1.2—Inspection Prior to Moulding

Resins and Glass Reinforcements:—

Check the various materials comprising the resin system, the catalyst/accelerator contents of the gel and lay-up mixes, the pigment loadings, alterations to the resin viscosity, etc., with the approved data sheet. Check from sample resin mixes that the proposed proportions give the correct results. The reinforcements are checked as regards manufacturer, type, reference, weight, etc., normally by a visual check and by examination of the makers' labels.

Laminating:—

The proposed lay-up procedures and phasing should be discussed with regard to longitudinal or transverse lay-up, overlapping of reinforcements, sequence of the various types of reinforcement, method of building up local increases in laminate thickness, amount of material to be moulded before assembly of the half hulls and so on. These may have an effect on the approved scantlings and any necessary amendments can be made. Any moulding snags due to awkward shapes in the mould such as deep fins, fillet radii, spray chines, etc., should also be discussed.

For prototype boats or new methods or construction techniques, sample laminates may require to be laid up and evaluated.

Mould:—

The following checks should be carried out on the mould:

1. The mould sections should be properly assembled and aligned with sufficient bolts or clamps along the joints.
2. The overall shape and form examined for fairness, particularly where the mould is split through the centre of a panel such as the transom centreline, to ensure that the panel halves are in the same plane.

3. The mould surface is adequately supported and rigid enough to prevent movement during the moulding process. A certain amount of flexibility is normal in small hull moulds as this assists the release.
4. If the mould surface is of a poor standard or there are any local blemishes or unfairness, these should be brought to the moulder's attention. These are a matter between the moulder and his client as the Society are not concerned provided the finish will have no deleterious effect on the laminate quality. This is on account of the high costs involved in obtaining a good mould finish if it was not achieved when the mould was made.
5. The position of the mould in the shop should be satisfactory as regards heat, draughts, sunlight, dust, etc. These conditions are normally dealt with in the approval of the works, but due to production requirements, the moulding area tends to get stretched to its limits.
6. Examine that the release agents are correctly applied on a dust-free mould surface.

5 . 1 . 3—Inspection During Moulding

Resins and Glass Reinforcements: —

Witness periodically the mixing of the resin system and check on the setting times of the mixes. The resin viscosity should be low enough to prevent serious drainage on vertical surfaces, but high enough to ensure satisfactory impregnation. Visual inspection of an unfilled resin reveals the presence of any impurities and any cloudiness will indicate that the resin contains dirt, water or other foreign matter. Rolls of reinforcement should be opened and spot checked for imperfections, dust, cutting table debris, etc., and if any are found the defective areas should be removed.

Laminating: —

Keep a continual and close surveillance on the handling of the materials and the moulding techniques. Ensure that the type of roller being used is achieving satisfactory impregnation and consolidation. Check that the phasing and sequence of operations are being maintained.

Check that satisfactory access is arranged, either by the moulding being rotated or some form of scaffolding being provided to allow the lay-up operators to work comfortably inside or over the mould.

5 . 1 . 4—Inspection After Moulding

Prior to release of the hull or deck from their moulds:

1. Ensure that the moulding has reached a satisfactory degree of cure before being released.
2. Check the need for any temporary bracing or support for the laminate during the release operation.
3. Check that satisfactory handling equipment and an adequate cradle are provided.
4. Check that the release can be carried out and that no damage from pulling blocks, chains and adjacent structure will not result during the moulding operation.

After Release from the Mould:

1. Examine the moulding immediately on release for any areas of non-release and undercure, and also other surface flaws. The outer surface should be examined by sighting along the surface as any local undulations or dullness can be quickly spotted and marked for attention. This visual check is then followed up by tapping the surface, paying particular attention along knuckles such as transom boundary, chine lines, etc., where voids can be anticipated.
2. Check that any necessary support or protection is provided for the moulding, particularly the deck, to ensure that it is not overstressed or damaged while in a partly supported state during the fitting out operation.
3. Carry out a check on the laminate thickness which will normally only be by the feel of the laminate and the physical measurement of accessible topsides, or by examination of off-cuts for pipe fittings, ports, etc.
4. Ensure any post-cure requirements are complied with and that there has been a sufficient lapse of time before the moulding is transferred outwith controlled conditions.

5 . 2 SURVEY PROCEDURE—EXISTING YACHTS

5 . 2 . 1—Overall Inspection

The logical starting point of a survey of a yacht which has been in service is to have a general overall look at the outside surface of the hull. If the survey is to be thorough the hull should be out of the water. Areas of distortion of the hull surface, evidence of local damages, local cracking, unexplained wetness or weeping and rust streaks or other discolouration of the hull should all be noted. When any of these defects exist on the outside of the hull, the interior surfaces in the affected area must be carefully examined for further damage and to determine the cause of the problem. There will, of course, be parts of the interior of the yacht which cannot be inspected without some disruption of the internal joinerwork. From the overall examination, the Surveyor can determine which areas of the hull must be subject to a much closer examination.

In making this evaluation of the hull, it is extremely helpful if, from previous yachts of the same type, information as regards common defects and the reasons for the same and also of areas where difficulties have been experienced.

5 . 2 . 2—Detailed Examination

A thorough examination should then be made of the hull laminate and framing of all areas physically accessible. It should include an intensive search for areas of stress concentrations in way of holes and other openings. Also in way of any abrupt change in the size and shape of a stressed member, such as a longitudinal or bottom girder, or where there is an abrupt change in a deflected shape caused by a rigid member ending on an otherwise flexible hull panel.

Areas which are subject to a large number of repetitive loads, such as engine seatings and the bottom structure of power boats should be examined for cracks or delamination. Any deck or shell area which vibrates excessively when under way may also be subject to fatigue cracking.

Special attention should be given to areas which contain encased wood or other materials.

Service experience has shown the deck to hull connection as the most troublesome joint which may cause a loss in the overall strength of the hull and lead to progressive failure of the deck or shell. This connection is, of course, subject to frequent impact damage when coming alongside. Other joints that should be examined are the hull centreline joint, centrecase joint, bonding-in of bulkheads and other assemblies and, of course, the boundary of tanks.

Attachments to the hull should also be checked, especially where they support heavy loads as in the case of bitts, chocks, chain plates, grab rails, stanchions, etc. The type of fastenings

and the backing reinforcement in way of the attachment should be examined.

There are certain damages and defects which obviously render the hull unsuitable for use and must be repaired. Such damages as a hole in the hull due to collision or grounding, or failure of a chainplate, carrying away of a stanchion, deck to hull connection and attachment of the propeller brackets are typical examples. In general, the results of damage due to physical occurrence, such as collision and heavy weather, are relatively easy to assess.

Faults inherent in the design and construction of the boat are far more difficult to evaluate. Defects are present in some degree in all laminates and items such as voids, internal local delaminations, resin rich and resin dry areas may be found. The seriousness and the location of the defects must be assessed and also the degree of repair which will be necessary.

5.3 METHODS OF INSPECTION AND TESTING

5.3.1—Methods of Determining the Laminate Quality

The methods of determining the quality of laminate can be divided into non-destructive or destructive. The first group being the only methods readily available to the Surveyor and are given below:—

1. The most obvious and simplest method is visual inspection, either under natural light or assisted by transmitted or reflected light from a powerful inspection lamp. Transmitted light is particularly useful as a good laminate will appear uniformly translucent whilst certain defects are shown by specific indications. However, certain slight variations in light intensity can be due to non-defects such as variations in gel and laminate thicknesses, reinforcement overlaps, etc. Unfortunately, in most yachts the pigmentation of the gel and more so, of the lay-up resin, makes the detection of internal defects extremely difficult or impossible.
2. Sound is another useful test. A good laminate when tapped with a hard light metal object, such as a coin or a light hammer, gives a clear hard sound. A dull or muffled sound will indicate that undercure or poor impregnation are present or that delamination has occurred.
3. From the feel of a laminate, the presence of any surface tackiness will indicate that the surface resin is undercured. This does not necessarily mean that the laminate beneath the surface is also under-cured.
4. The final method is smell as a strong odour of styrene will indicate insufficient cure of the laminate or under-cure depending on the time expired since lay-up.

Much time and research work has been spent in recent years in attempts to develop a single non-destructive test for the evaluation of a laminate. Many interesting proposals have been made but to date there is no simple satisfactory test which meets all requirements. Current research is working along the following lines:—

1. Ultrasonics is one of the most promising and involves transmitting very high frequency sound waves through the laminate and measuring the attenuation of the sound and its velocity of transmission. Preliminary investigation indicates that the number of voids and the glass content can be evaluated by comparing these values with known standards. While this method is not presently available to the Surveyor, it is being successfully used by a few moulders and shows promise for the future.
2. The use of X-ray and fluoroscope methods have been tried but results indicate that these methods are not satisfactory because density differences between sound and unsound areas of the laminate are apparently too small to be reliably detected.
3. Other methods, such as the use of penetrating dyes, various types of radiation and heat sensitive phosphors have also been tried and although successful in the laboratory, they have not been sufficiently developed for commercial use in the field.

The most reliable method of determining the laminate quality is by destructive tests carried out by a laboratory. The mechanical properties of the laminate are determined by subjecting specimens to the standard tests, several specimens being tested for each property to obtain average values. Chemical tests form an essential part of quality control and are used to determine the resin properties. Specimens should be cut from within the laminate to avoid edge effect and also when the laminate has reached maturity.

Certain physical tests may sometimes be required but it is current practice to keep destructive testing to a minimum. As previously mentioned sample panels are seldom representative of actual hull laminates and the removal of samples from a finished moulding necessitates costly and undesirable repairs. Any test pieces incorporated into the mouldings, however, should not be defined as test areas and so avoid any special treatment during lay-up.

5.3.2—Methods of Assessing the Degree of Cure

When a polyester resin gels from a liquid to a solid at room temperature, the polymerisation reaction may continue for a long time, perhaps for several weeks or even months. If the reaction terminates prematurely the laminate will be undercured and the mechanical properties will not be realised and the durability of the laminate will be poor.

No satisfactory solution has yet been found for the assessment of cure. The only non-destructive test available to the Surveyor is the Barcol hardness tester which measures the surface hardness of the laminate, the resulting value being compared with a known standard. This instrument is portable, quick and simple to use, but although satisfactory on a small production item, it is not so convenient on the larger hull where a few hundred readings are necessary.

A national committee has been sitting since 1953 in an effort to find a simple and reliable test. It is possible to get a near approximation if a series of tests is carried out in a laboratory on a reasonably sized offcut, but these tests take time and they would not be suitable for routine testing. To do this the following tests are carried out and provided the results are intelligently interpreted, a fairly reliable assessment can be made.

1. Tan δ at 1000 cps.
2. Dielectric constant.
3. Water absorption, leaching and swelling.
4. Benzol absorption, leaching and swelling.
5. Acetone soxhlet extraction.
6. Barcol hardness.
7. Ball rebound.
8. Starch/iodide test.

5 . 3 . 3—Assessment of the Laminate Thickness

There are no readily available means yet of measuring the thickness of a finished hull. Large calipers can, of course, be used along the top edge where there is ready access, but for the rest of the hull the measurement can only normally be done by one of two methods.

The first is the somewhat drastic step of drilling small holes at various important points and, after measuring, filling the holes with a suitable material. The other method is to use one of the meters available for the measurement of paint coatings. However, as these instruments measure the gap between the electromagnet and a steel plate, such a plate must therefore be held on the opposite side from the probe and as can be imagined this is not easily done in the case of a yacht hull. One-sided measurement can be done with ultrasonics but such equipment, as indeed with the paint meters, is usually beyond the resources of the boatbuilders.

A comparison of the measured thickness with the calculated thickness will give a reasonable indication of the resin/glass proportions. Where the types and numbers of plies of reinforcement are known, the thickness can be calculated from the nominal thickness per ply for each reinforcement as given in Table 1. As the hull will usually consist of two or more types of reinforcement, the total expected thickness is determined simply by adding together the thickness of the various layers. As shown in Fig. 1 the thickness of the gel coat and of the interior finish must be deducted from the total measured or calculated thicknesses to obtain the effective thickness.

Laboratory tests must be made on laminate samples if the types of reinforcement, resin/glass ratio and the strength are to be accurately determined. The type and number of plies of reinforcement are determined by burning off the resin and by weighing the sample before and after burning, the resin/glass ratio can be obtained.

Material	*Resin/Glass Ratio*	*Thickness*	
2 oz. (600 gr.) Mat	3 : 1	·060 in.	1,5 mm.
2 oz. (600 gr.) „	2½ : 1	·054 in.	1,5 mm.
12 oz. (400 gr.) Woven Roving	2 : 1	·017 in.	0,4 mm.
16 oz. (530 gr.) „ „	2 : 1	·023 in.	0,6 mm.
22 oz. (700 gr.) „ „	2 : 1	·031 in.	0,8 mm.
27 oz. (900 gr.) „ „	2 : 1	·038 in.	1,0 mm.

Table 1

Approximate thickness per ply of reinforcement.

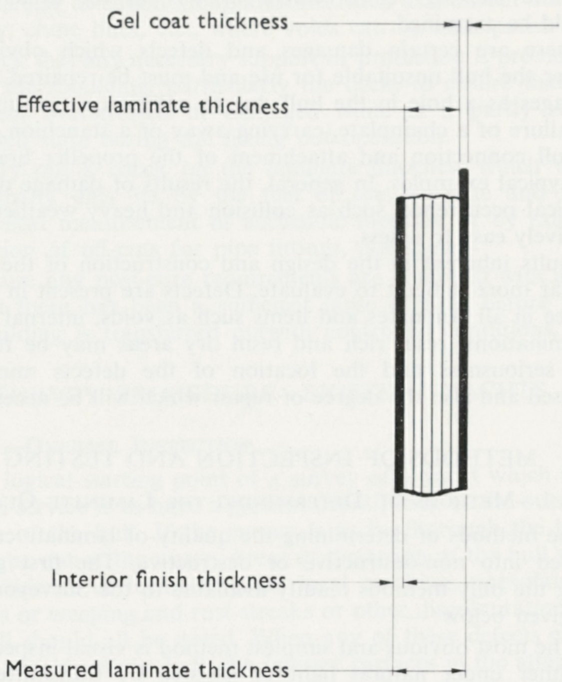


Fig. 1

Effective laminate thickness.

5.4 FABRICATION ERRORS

5 . 4 . 1—Fabrication Errors—Resin

Polyester resins are formed by the condensation of various glycols with an unsaturated dibasic acid and a saturated dibasic acid. The polyester thus formed is then blended with monomeric styrene. Significant variations in resin performance result from slight changes in the proportions of the component and the conditions of reaction.

Under existing arrangements these factors are entirely outside the knowledge of the Surveyor and short of specifying the preparation of a series of test laminates he must accept the resin as a potentially satisfactory material. The resins can be specified to be in accordance with a suitable standard specification but it is clear that even this will not make the resin aspect entirely satisfactory from the Surveyor's viewpoint.

The resin is, however, merely the start of the problem. The resin mix also contains in addition quantities of catalyst, accelerator and pigment and also perhaps fillers. The manufacturer's technical literature gives recommendations for the amounts of these additives which may be used and the choice finally made by the moulder is normally based on a mix which gives a pot life suitable for his laying up process.

Apart from the obvious error that someone forgot to add either the catalyst or the accelerator, or even both components, an error can still occur by incorrectly measuring or weighing the materials. For this reason, it is desirable that the number of operators who actually mix the resins should be restricted and, if possible, some central mixing bay should be provided. "Good housekeeping" in such areas is imperative as dirty measures, mixing cans, etc., can not only introduce foreign matter but can also lead to short measure if volume measure is being used.

Similarly, large quantities of unmixed resin should not be left open to the atmosphere to collect dirt, moreover, unmixed polyester resin can thicken and even set hard when exposed for long periods to bright sunlight.

Normally, most resin manufacturers do not guarantee a shelf life for all their products in excess of six months provided it is kept in closed containers at normal temperatures of below 68° F. (20° C.). Any resin which has been kept beyond this time should be treated with suspicion and only used for important structural items if proved satisfactory by a simple laminating test.

Thorough mixing of the catalyst and accelerated resin is also of importance and is even more important when the

catalyst is a liquid such as MEKP rather than a paste or a powder. This paradox arises because a paste or powder is more difficult to disperse and can be easily seen, whereas a liquid appears to disappear after a few moments stirring but may separate on to the surface of the resin on standing and not be noticed.

The amount of filler in the structural laminate is restricted to 25 per cent of the weight of actual resin in the mix. Unfortunately, an excess of filler is not easy to detect visually because the moulding often looks perfectly satisfactory until it has been exposed to weathering for about 18 months. Fairly simple tests in the laboratory on offcuts or coupons can, however, give an assessment of the filler content especially when this is calcium carbonate.

Surface tackiness of any laminate must, of course, be viewed with suspicion unless the attack disappears within a very short time either by natural ageing or under radiant heating. Always be suspicious of surfaces which have been rendered tack-free by wiping with solvent; in any case beware of surface contamination by dirt pick-up caused by stickiness of the surface.

5.4.2—Fabrication Errors—Reinforcements

The reinforcing mat consists of short lengths of glass fibres bound together in a heterogeneous manner with a binder. There are several sources of mats with the nature of the binder varying from maker to maker. A soluble binder is normally used in boat construction as the binder is sufficiently soluble in styrene to enable the polyester resin to wet the glass fibres thoroughly and so to form a good strong laminate. This solubility must not be too high otherwise the fibres will become free and prove difficult to roll out.

Although the mat is usually of a high quality nowadays, occasionally small areas of unevenly distributed glass fibres are found. These appear whiter than the rest of the mat and this whiteness becomes more pronounced when the resin is applied because the area does not wet out. The areas must be cut out otherwise a resin starved area with consequent blistering or delamination will occur. On the other hand, uneven fibre distribution can also result in thin areas which may require a local addition of further mat during lay-up.

Sometimes the mat as supplied may contain "tramp" materials such as wood chips, etc. In any case it readily picks up foreign bodies such as dust and dirt in the moulding shop and this possibility should always be borne in mind as a source of defects. Good storage and handling arrangements and competent supervision are again the best defence.

5.5 LAMINATE DEFECTS AND SURFACE FLAWS

5.5.1—General

Faults which occur in plastic components are of two distinct kinds and although the presence of both presents problems, the latter type is the more serious as it usually occurs in service.

(a) Those defects immediately visible after release from the mould, and

(b) those defects that appear with age when the structure is stressed or weathered.

The causes of defects of the latter type are, of course, much more difficult to assess as no background information on shop conditions and practices is generally available. Normally the only way is to forward samples for chemical analysis to the resin manufacturers.

Apart from voids, defects and flaws in a new hull are comparatively rare such that when one does occur the moulders and the surveyor may have difficulty in attributing the cause purely from lack of experience.

A list of defects and surface flaws which may occur is given below and each defect is then discussed in detail.

Laminate defects—voids
blisters
crazing
leaching
delamination
internal dry patches

Surface flaws —voids
blisters
crazing
wrinkling
poor adhesion of gel coat
poor wetting-out of gel coat
too thick a gel coat
surface pinholing

It will be evident from the following sections how often the same possible causes keep cropping up and on the basis that prevention is the best cure, attention should be paid to the following arrangements.

1. Careful attention to workshop conditions particularly humidity and draughts.
2. Avoid contamination of the resins and glass materials.
3. Be consistent with catalyst/accelerator practices and with curing practices.
4. Use of suitable rollers to work air out of laminates.
5. Use of wrong type of resins and glass reinforcements.

Fortunately, many moulders work on the principle "better the devil you know, than the devil you don't know" and are reluctant to change from tried and tested materials to new materials without full assurance from the manufacturers of trouble-free moulding, so item 5 above is not so applicable nowadays to, say, three or four years ago.

5.5.2—Voids

Air bubbles, or voids, occur on the surface or within a laminate in varying sizes and concentrations. They are the result of either poor wetting-out of reinforcement, air entrapment between plies during lay-up, release of volatile components from the resin during cure, or excessive air inclusion in the resin possibly from mixing.

Voids and air bubbles in small amounts will occur in most laminates and cannot be eliminated, but by careful fabrication technique, can be kept to a minimum of about 2 to 3 per cent of the laminate volume. Surface bubbles will impair the appearance but internal bubbles, if numerous and bunched, indicate areas where the laminate has a high rate of porosity. Major amounts, particularly when interconnected, will appreciably impair physical properties, while minor amounts appear to have no effect. Bubbles are detected by visual inspection with either reflected or transmitted light. Surface voids can be found by tapping (*see* Fig. 2).

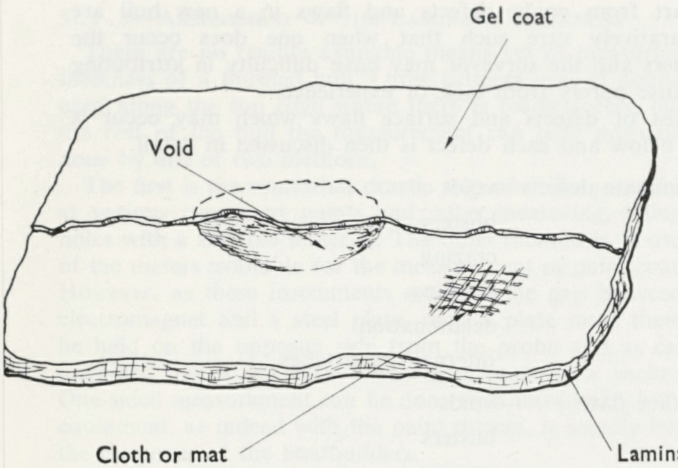


FIG. 2

Surface void.

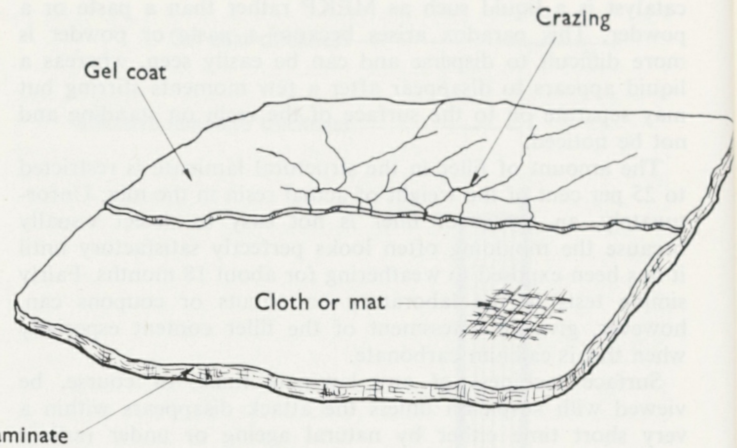


FIG. 3

Surface crazing.

5 . 5 . 3—BLISTERS

Blisters on the laminate are an obvious indication of local delamination and are caused by entrapped air or solvent. If they extend over a considerable area it may indicate too rapid a cure, usually due to an excessive amount of radiant heat during the curing process. If, on the other hand, the blister is below the surface, the cause could be either the use of an unsuitable mat containing an incompatible binder or failure to work the air out of the reinforcement by the resin during impregnation.

5 . 5 . 4—CRAZING

Crazing in a laminate is an indication of localised bond failure between the resin and the reinforcement. It will tend to give a hazy translucent appearance in the laminate of a minor attack, or if more severe as a "whiteness" occurring in a definite pattern along a given ply and appearing like a watermark. It may be due to contaminated reinforcements, fabrication under conditions of excessive humidity, failure of unreinforced resin due to excessive heat during cure, or to large concentrates of catalyst and accelerator. Crazing in a laminate is an indication of undercure.

Surface crazing can occur immediately after moulding or long after the hull is in service. It appears as fine cracks in the resin, which are seen more easily if viewed obliquely, extending as a network over the surface. These surface cracks are structurally unimportant and affect only the boat's appearance. They are nearly always associated with resin-rich areas and may be caused by defective formulation or mixing of the resin. If they are present in a gel coat of not abnormal thickness, the use of either too much styrene or insufficient plasticiser in the resin may be suspect. They may also be the effect of some form of stress, their pattern indicating the direction of the stress, or may have been caused by an attack of resin by a solvent or other chemical (*see* Fig. 3).

5 . 5 . 5—LEACHING

Leaching is the apparent loss of resin from the laminate surface leaving the reinforcement exposed. It occurs only in the course of time and is caused by the exposure of an insufficiently cured laminate to the effect of water immersion or by regular exposure to heavy rain or spray. The reasons for the under-cure could be:—

(a) moulding shop temperature below 60° F.

(b) an excessive loss of styrene monomer.

(c) the presence of inhibitors.

(d) the use of an unsuitable type of polyester resin.

If allowed to continue, the effect of leaching is most serious and could eventually destroy the watertightness of a craft. Any craft that are stored outside within a short period of being moulded, often necessitated by production floor space requirements, should be suitably covered against rain.

This defect should not be confused with another phenomenon, "fibre pattern", which is not at all deleterious. This latter effect is common with resin/mat constructions and will also appear with age. In this case, however, the resin surface will still be intact and glossy and the glass fibres, although visible, will be embedded in the resin.

5 . 5 . 6—DELAMINATION

Delaminations are areas in which the bond between the adjacent plies in the laminate has failed or was never achieved. Failure to achieve a good interply bond may be due to contaminated reinforcement, or to an excessive exotherm and shrinkage during cure. Delamination after cure is usually due to excessive stress and may be caused by local impact or by forcing or springing the laminate into place during assembly. Delamination around bolt holes may be caused by excessive drill pressure or too rapid drilling of the hole, by aligning with drift pins, or by excessive tightening of the bolts.

This trouble can be seen by transmitted or reflected light, the whiteness of the delamination slowing up uniformly if before cure and if after cure, in varying intensity towards the point of impact.

5 . 5 . 7—INTERNAL DRY PATCHES

Internal dry patches are characterised by the appearance of a whitish weave or fibre pattern and may be caused by either insufficient resin, poor resin distribution, improper surface treatment of the reinforcement or a gel time too short to allow the mat to wet out. They are also an indication of poor

fabrication technique as they may be due to the operator trying to impregnate more than one mat at a time. Such laminates are usually found in areas which were hard to reach during the fabrication procedure and on vertical surfaces due to excessive resin drainage.

5.5.8—Wrinkling

Wrinkling is also known as "fuzzle" or "triping" and occurs in gel coats. It may result from one or more of the following:—

(a) The use of a resin in the gel coat which is insufficiently cured to prevent an attack by the styrene in the subsequent application of resins.

(b) The loss of styrene monomer by evaporation and causing the gel coat to be undercured.

(c) If the wrinkling is on the vertical surfaces of the structure only and the horizontal ones are free of it, then it is quite possible that the gel coat was too thin and did not cure fully.

The last two causes are of particular importance because of the greatly reduced water resistance of undercured gel coat surfaces which cannot be considered acceptable for immersion in water or exposure to rain.

5.5.9—Poor Adhesion of the Gel Coat Resin

Unless the degree of adhesion of the gel coat is markedly poor, this defect is often only noticed when the structure is being handled and areas of gel coat break away. Sometimes areas of poor adhesion can be seen by the presence of a blister on the gel coat but more often they can be detected by local local undulations in the surface when viewed obliquely.

The cause of this defect is usually the use of an unsuitable resin for the gel coat which hardens too rapidly. Further but less frequent causes are contamination of the gel coat before the glass reinforcement is laid up or an inadequate consolidation of the laminate on to the gel coat.

5.5.10—Poor Wetting of the Gel Coat Resin

Poor wetting of the gel coat resin is known as "fish eyes" and is characterised by largish depressions or small cavities in the surface. The defect is usually due to an abnormal amount of release agent on the mould or can sometimes be attributed to the use of an unsuitable gel coat resin having too low a viscosity.

5.5.11—Too Thick a Gel Coat

Too thick a gel coat is self explanatory. The skill of the operator is one of the most important factors in overcoming this defect but he can be given some assistance by the selection of the best formulation of the gel coat resin for the particular job. Unfortunately the presence of too thick a gel coat may not be seen immediately but starring and cracks in the surface will appear should the structure receive an impact or be severely flexed.

5.5.12—Surface Pinholing

Surface pinholing is mainly associated with fabric reinforcement but has been known to occur with mat reinforcements especially when heavily filled resins are being used. As these fillings may be antimony oxide for fire resistance, this defect may occasionally be met on structures which have this property. Whilst the presence of mould release agents such as silicones can be a cause, the more usual explanation of this defect is either the entrapment of air or an inadequate dispersion of the fillers. A more thorough stirring of the mixed resin is an obvious remedy for the last cause and, if this is followed by a short stand for the air bubbles to come out, little trouble should follow.

If, despite these precautions, the defect still occurs because of release agent troubles, the problem can usually be overcome by the use of the two-release agent technique.

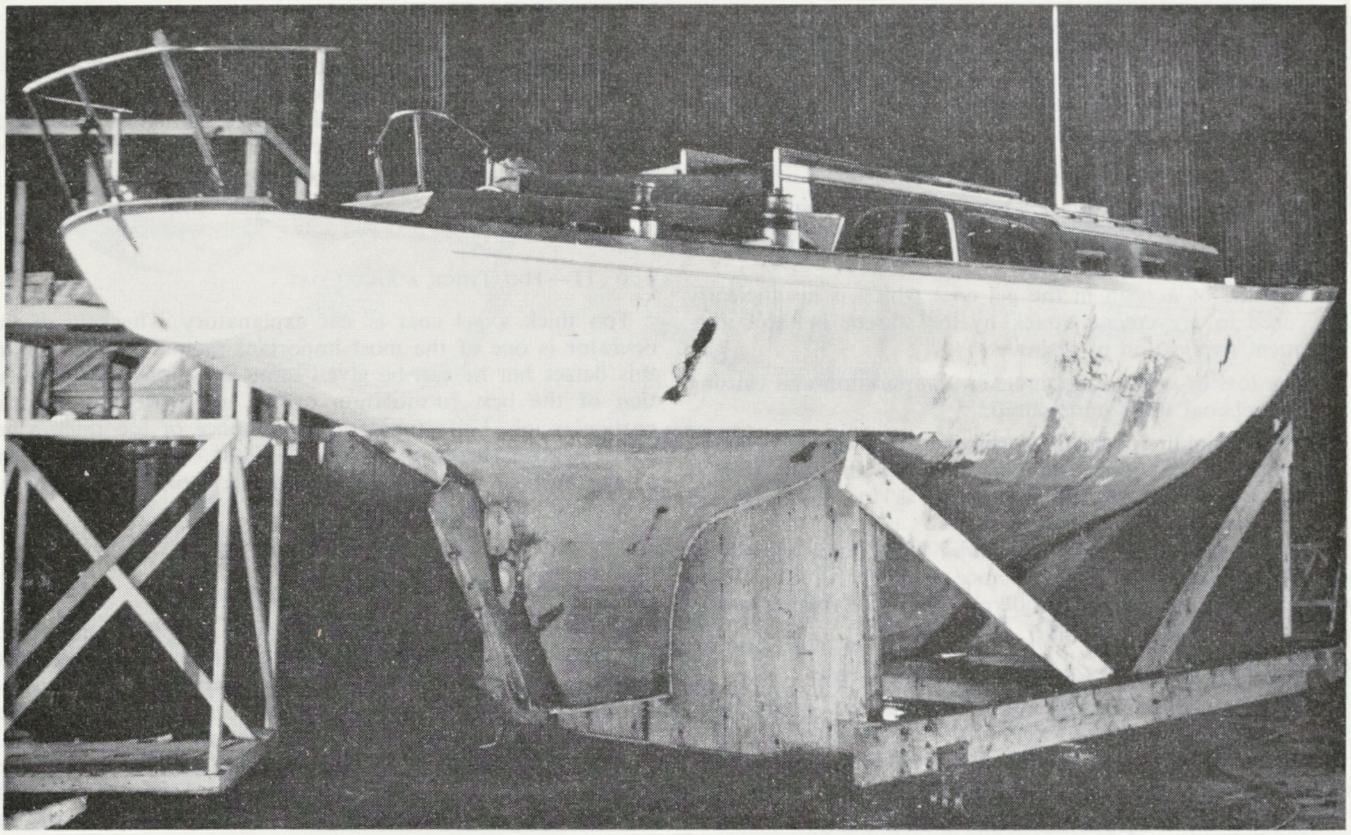


Fig. 4

Damaged yacht on arrival at repair yard.

PART 6—REPAIR AND MAINTENANCE

6 . 1 REPAIRS

6 . 1 . 1—General

One of the major advantages of plastics construction is the relative ease with which high quality repairs can be made. Also the repairs can be carried out in far less time than in conventional wood or steel craft, a point which stands out in favour of G.R.P. craft for working boats since, in addition to the reduced cost of repairs, the time lost is also less. The plastics hull has virtually no internal stress and so when subject to impact loading, it will either deflect and return to its original shape or there will be a definite localised break. Even large areas can be damaged and the hull will retain its original form. This was the case with the 38 ft. yacht shown in Fig. 4 where the damage was found to be more extensive than appeared at first sight (*see* Figs. 5 and 6). This craft had sustained pounding on rocks under storm conditions for many hours and it is considered that whereas the damage remained localised in the plastic hull, it would have rapidly weakened and broken up a wooden craft. As hull damage is restricted to a small area in the vicinity of the impact, the major portion of the damage repairs are in replacing the joinerwork interior. The impact forces cause the bunks, bulkheads and cabin soles to break loose from one another and from the hull.

Large extensive repairs are carried out under the controlled conditions of a moulding shop as given in Part 2 of this paper.

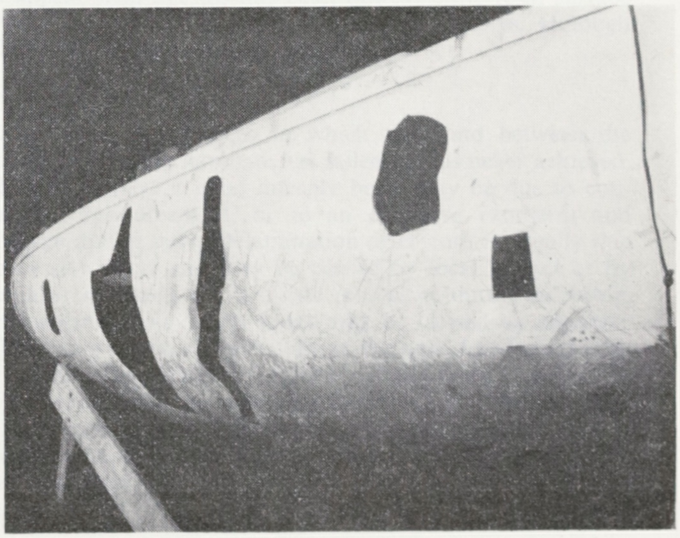
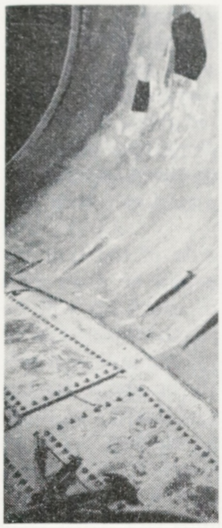


Fig. 5

External view of starboard side amidships showing damaged areas cut away.



Inside of hull pre

Less extensive repair
building with warm
or tenting arrange
draughts, dust, etc.
and handling arrang
with particular emp
reinforcements by m
that repair personne
and are adequately
achieved.

Hull repairs fall
gories:—

1. Rectification of
during moulding
damage in servic
2. The repair of m

6.1.2—Minor Rep

The majority of m
such as blisters, resi
and, if spotted, can l
boats in service are
and scratches whicl
attention. The loose
the damaged area li
dried. Drying may
small amount of r
evaporate.

For superficial da
polyester or epoxy re
and allowed to set.
the resin in position
repaired patch has h
the correct hull cont

Where deep scratc
laminate, layers of a
and of reinforcemer
beyond the area of
illustrated in Fig. 7.

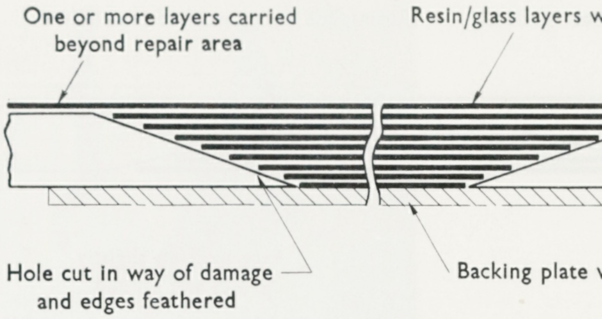


Fig. 9

Repair from the inside of hull of a penetrating

laminate bearing in mind the type of reinfor
period of immersion. The edges of the hole ar
back for several inches on the inside of the h
sander, and any corners of the hole are rad
rounding parts of the repair area are thor
degreased and dried.

A temporary mould or backing plate of ply
sheet metal or other suitable material, is se
hole. Release agent is applied to the backing
by a gel coat and then layers of reinforcemer
resin using the same method as in the ori
When the repair has been laid up to the same
adjacent structure, several further layers of r
overall extending for several inches in all di
the repair. Any frames, longitudinals, etc., in w
in much the same manner using suitable f
the cellophane film is applied as a protection
cure.

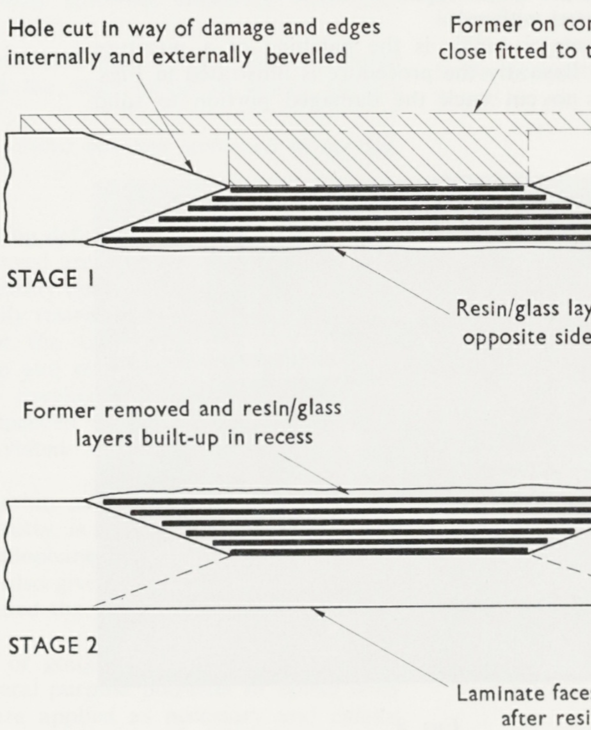


Fig. 10

Double scarph repair of thick laminate

xcellent results. The epoxy paints are con-
answer to reconditioning boats at the present

ılkyd paints are easier to brush out, and their
ot critical to temperature as with the epoxy.
retains its original lustre longer. They generally
primer to guarantee proper adhesion, although
ı successfully applied without the primer in
ve been in service due to the slight etching of
due to weather. These paints, however, cannot
aces recently repaired with epoxy based putties
ibiting action of the faint exudation of free

ɴg of the Bottom

is resistant to sea water, and to attack by
such as gribble and toredo. Barnacles and
ı themselves to the hull below the waterline
anner as a wood or steel hull, but they are
to clean off. Normally a hull is anti-fouled,
ches which have been working in warm waters
w years have never been painted with anti-
ıormal practice was to be slipped every three
aned off with a wooden scraper.
od adhesion of an anti-fouling paint has been
the manufacturers have now developed special
ıint systems to avoid the peeling which was
rienced a few years ago, the cause of most of
ıg the thin invisible film of wax release agent
Section 6.2.1. On a new boat, the bottom
ared as before, but on the boats which have
less surface preparation is necessary as the
s disappeared and slight etching has occurred.
boats, the bottom paint is applied direct with-
the primer specified by the manufacturer.

of Surface Finish

d gel coat on the hull and deck is designed to
and appearance for a number of years.
uite durable, it should receive reasonable care
er and fade. The surface finish will, however,
look better if washed regularly and periodi-
th a normal car polish. Ordinary household
washed away afterwards. Caustic washes are
w of alkaline attack on the gel coat surface.
down with a cleaner is necessary if the finish
o the point that there is considerable fading
chalky film condition.
pattern on the deck is cleaned with a stiff-
and a cleaner. Any grease marks can be
a deck brush and petrol. The deck surface
rmally need any further annual treatment,
ıairing odd gouges by dropped deck gear, etc.
e repaired by grinding the damaged pattern
aminate, then applying matching resin and
ıtch of the original transfer material.

PRINTED BY LLOYD'S REGISTER OF SHIPPING
AT GARRETT HOUSE, MANOR ROYAL
CRAWLEY, SUSSEX, ENGLAND

FOR PRIVATE CIRCULATION AMONGST THE STAFF ONLY

Lloyd's Register Staff Association

Session 1964-65

Paper No. 6

Discussion

on

Mr. A. McInne's Paper

GLASS REINFORCED PLASTIC BOAT BUILDING—Parts V and VI

LLOYD'S REGISTER OF SHIPPING

71, Fenchurch Street, LONDON, E.C.3

Discussion on Mr. A. McInne's Paper

GLASS REINFORCED PLASTIC BOAT BUILDING—Parts V and VI

The Author is very grateful to all who have contributed to the discussion and for ease and convenience in reference, he has re-arranged some of the contributions under the various sections and hopes this will meet with the contributors' approval.

SURVEY AND INSPECTION

MR. W. L. HOBBS (Southampton)

Although the Author lays down survey procedure for new construction, unless the surveyor is practically "resident" with the firms concerned, it is well nigh impossible to follow the procedure advocated. For instance, it is not always possible to be in attendance immediately after a specific hull has been released from the mould, especially in cases where firms are producing several hulls at one time.

If the procedure the Author lays down is to be taken as "Instructions to Surveyors", then the Society will need to recruit extra survey staff without delay, for reinforced plastic boat builders are springing up like mushrooms.

MR. G. R. MAY (Headquarters)

As the moulding of a reinforced plastic yacht hull and deck is completed in a very short time, it is of great importance that the relationship between surveyor and yard is very close. Before the moulding of a new type of yacht is commenced, a discussion should be held between surveyor and management as to the general procedure regarding resins and lay-up to be adopted.

Many firms are now working a bonus scheme for their employees. This could lead to a lowering of the standard of laminating and because of this a counter-scheme should be adopted by the management to prevent this occurring.

There are many schemes in existence at the moment. One very good scheme being used is inspection at several stages during the laminating by the yard manager and at each inspection a number of points awarded for each stage with a final check being made on the glass to resin ratio of the completed laminate (the figures being taken from records of materials used during the laminating).

Although the system uses the points for each individual laminate, if any defects are found the overall bonus of the shop is affected. This helps to maintain a very good general standard.

MR. S. SANDERSON (Copenhagen)

There has through the years been a limited number of papers which stand out amongst the others because they, apart from giving valuable information about the subject they are dealing with, are written in such a way that they have proved to be very useful as sort of "hand book" for the surveyors occupied with the subjects. If one only looks at the copies of these papers lying on the suveyors' desks, it is found that these are the most "Isabella"—coloured and ragged ones.

I believe that parts V and VI will be amongst those papers in the years to come, especially for the new surveyors on G.R.P. boat work, who are bound to be found occupied with this work in the future.

Regarding the paper itself I have only a few remarks:—

A colleague of mine said after reading the paper that he thought that G.R.P. work was not suitable for classification as the surveyor could in reality only have a very slight knowledge about the strength and workmanship of the items he was reporting on. I pointed out that we were in somewhat the same position when we switched over from riveting to welding. The rivets we could count, measure and hammertest, but of what was inside the welded butts and seams we had very little possibilities to test in the actual hulls. Yet, we are to-day quite satisfied with the results and have learned that there are many ways of controlling the work and in my opinion, a considerable part of this surveying work is kind of psychological.

It may be that in future the surveyors for this sort of work should not be picked out just because they are the most handy, but with a fair amount of regard to their special interest in the subject, their age and experience in surveying work, especially with regard to knowledge of the human nature.

We must bear in mind that the builders' knowledge about this kind of work, especially when commercial boats of larger sizes are coming into fabrication, is not much better than that of the surveyor and there is not an old tradition connected to the craftsmanship.

MR. J. I. MATHEWSON (Hong Kong)

As one of the surveyors who found himself suddenly faced with the supervision of the moulding of small craft of an unfamiliar material in addition to his normal duties, as described by the Author in the introduction to Part I, I can confirm that this series of papers has already proved itself to be a most invaluable reference on plastic boat construction. The Author is to be congratulated on his methodical and rational presentation of this rather specialised branch of boat-building. My contribution will be confined to a request for yet more information together with a few remarks on techniques applicable in Hong Kong.

Would the Author care to comment on the possibility of extending the series production/type approval certificate to hulls of more than 23 feet (7 metres) in length where these are manufactured on a production line basis, by the substitution of destructive mechanical and chemical tests in lieu of drop and deflection tests.

(We have considered raising the upper limit of length to 30 feet (9 metres), but this would prove difficult to operate at the present. Such a scheme would be acceptable at some firms, but at the most, the small numbers being produced would make it uneconomical. The situation may, however, change within the next few years, as each year shows a slight increase in the average length of plastic hull.—Author.)

5 . 1 . 3/4—Inspection During and After Moulding

Mr. J. I. MATHEWSON (Hong Kong)

In Hong Kong the climate during the winter season is such that moulding can be carried out successfully out of doors but during the summer when the temperature may rise to 95° F. and the relative humidity to 92 per cent a fully air-conditioned workshop with dehumidifier is essential. The temperature and humidity level should also be low enough to provide suitable working conditions since it has been found that the "honest sweat" dripping from the bodies of the perspiring workers may inhibit the satisfactory cure of the resin.

At this port all hulls from 7 ft. 6 in. to 60 ft. 0 in. are moulded in one piece thus eliminating problems of misalignment and jointing.

Satisfactory release of the large size hull is ensured by flooding with fresh water, through a brass cock low down in the mould, until the hull floats free. Water has been found to give a more even distribution of pressure than compressed air.

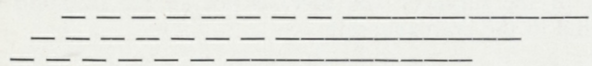
With regard to the general sounding of the hull by tapping a short length of stiff rubber hose has been found satisfactory whilst a coin on edge may be used for the awkward corners such as the recess in the rudder post, etc.

Mr. S. SANDERSEN (Copenhagen)

A firm in this country having made G.R.P. yachts and lifeboats for quite a number of years uses a method of laying up the laminates by hand which might appear unusual but has proved to be very effective.

The hulls are made in two halves and hence the laminates are layed up practically horizontal.

The mats are laid up three at a time, thus:—



and when the next three layers are fitted the edges overlapping the first layers are not cut to size but torn by hand. The advantage of this method is that the foreman can always control the number of layers and due to the one edge being torn the "butts" of the various layers can scarcely be seen, when the mats have been properly rolled and the appearance of the inside of the hull when finished is unusually smooth. Of course, it takes a little practice to get that result.

This method of tearing some of the edges can also be used for repair work where "covering mats" shall have the contours tapered off.

(The method of laying three or more layers at the same time and working progressively in this manner, from one end of the hull to the other, is referred to as the "shingle" technique and gives a slightly thinner and smoother laminate than the conventional manner.—Author.)

5 . 2 . 2—Detailed Examination

Mr. A. LINDQUIST (Abo)

Some moulders encase quite a lot of wood in their boats and I would like to know what experience there is of this detail. I have a feeling that encased wood sooner or later must absorb a certain content of moisture especially where used in connection with screw-fastened fittings and I wonder what happens after a number of years. In a cold climate this moisture would freeze every winter probably causing cracking of the wood and the laminate.

AUTHOR

We have no record of troubles being experienced due to water absorption of encased timber cores. However, discretion should still be exercised as such cores should be kept clear of "wet" bilges, etc. In the case of plywood pads matted into the laminate, drilled holes should be resinated and liberal bedding compound used to seal off water access.

5 . 3 . 1—Methods of Determining the Laminate Quality

Mr. W. L. HOBBS (Southampton)

The sooner some mechanical or electronic devices to aid the surveyor to assess the quality of laminates are invented the better, for at the moment the visual and tapping tests are the only ones immediately available and although on existing yachts that have seen some service these tests give satisfactory results, for by that time hidden defects have come to light through expansion of air in parts of the laminate, or the bonds of bulkheads, chain plate anchorages, etc., may show signs of failure, it is often impossible to find these faults in a new craft without destructive tests.

Mr. A. LINDQUIST (Abo)

There is only one manufacturer here who has used resin without any colour pigment. When checking their mouldings we have wondered how many air bubbles we have passed in the approved hulls and I would like to know Mr. McInnes' opinion of what could be accepted as regards air voids. Clear laminates, of course, improve the workmanship very much and for big boats I believe the advantage of being able to inspect the hull properly is worthwhile and compensates the disadvantage that the hull has to be painted immediately instead of after three-four years.

Mr. J. I. MATHEWSON (Hong Kong)

The writer would welcome an Appendix giving details of the standard tests and test pieces for obtaining the mechanical properties of the laminate, also details of the chemical tests which are stated to form an essential part of quality control.

In tensile tests carried out at this port some difficulty was experienced in getting the standard jaws of the machine to grip the laminate without slipping.

AUTHOR

I can appreciate Mr. Lindquist's feeling on a pigmented laminate when he sees the number of voids in a clear laminate. A figure of 2–4 per cent is quoted as the normal volume of voids in an average laminate. The lure of the pigmented hull is too strong for most owners, and the best we can hope for is an unpigmented lay-up with a pigmented gel coat.

There has been very little progress over the past few years on standardising test methods and we are not yet in a position to give guidance on this matter. Very little production testing is done by the boatbuilders, this being restricted to the iodine test for cure. Even on the question of tensile tests, there is not yet an agreed size of testpiece.

5.3.2—METHODS OF ASSESSING THE DEGREE OF CURE

MR. J. I. MATHEWSON (Hong Kong)

Details of water absorption, leaching and swelling tests would also be appreciated in the Appendix.

Hot and cold water, and hot water boiling tests, such as are applied in plywood manufacture, are fairly simple to carry out without laboratory facilities and have been used for relative comparisons of various laminates.

MR. W. B. SCHEELINGS (Rotterdam)

A particular firm in Holland possess a Barcol hardness tester which has been used for checking the curing of the laminate of boats being moulded under our supervision. The figures found over a great number of tests varied between 50 and 75 after the boat had been cured for a minimum of a fortnight.

I would be very pleased to know whether for checking the accuracy of the tester, standard laminates were issued with the apparatus.

What results must be expected when being used on a gel coat, especially if a plasticiser has been added.

AUTHOR

The water absorption tests for which Mr. Mathewson is requesting details are comparative tests based on results from known standard laminates. The same method of preparation and of testing must always be used, otherwise variations in procedure could give entirely false indication of the laminate performance. These tests are normally only carried out by research and testing laboratories but are seldom done in production control laboratories.

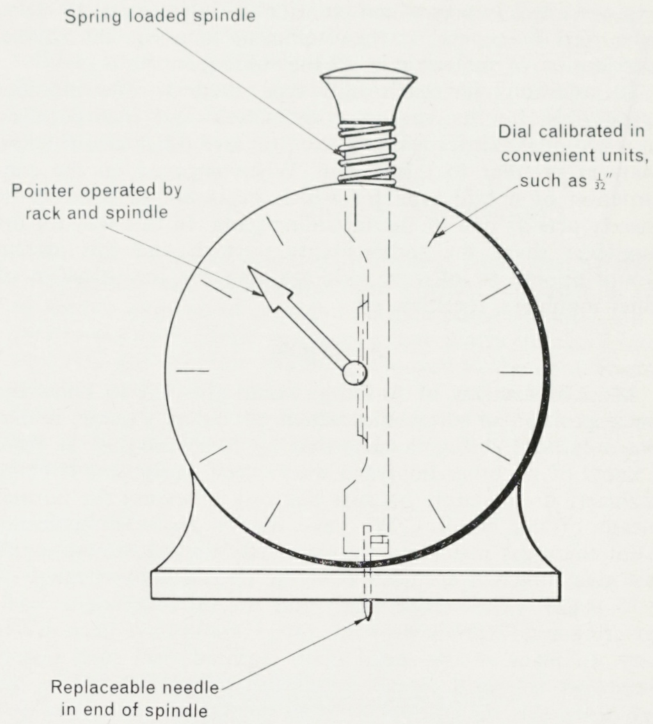
Mr. Scheelings remarks on the Barcol tester are of interest. To be entirely satisfied with a hull, many readings must be taken and consequently I consider a light tapping hammer to be equally discriminating and far quicker. The real value of the instrument is in establishing your basis hardness or "ring". Some resins, such as the flexible gel coats, have values just above 40 but the values can rise higher than the figures quoted where glass fibres are immediately under the probe.

5.3.3—ASSESSMENT OF THE LAMINATE THICKNESS

MR. W. L. HOBBS (Southampton)

Laminate thickness where chopped strand mats or woven cloths are used presents no real problem provided the builders are proved trustworthy in the early stages of their existence, but spray application even with highly skilled operators can be a tricky business in ensuring uniformity of thickness.

As the whole of the main lay up in the spray technique is carried out in one continuous operation, perhaps the simple instrument I have sketched out would prove effective, for once the sprayed rovings and resin are consolidated by rolling, it should be an easy matter to take spot checks on the thickness of the laminate by pressing the needle down until it hits the hardened gel coat and then comparing the thickness reading on the dial with the thicknesses shown on the approved plans.



Instrument for measuring the laminate thickness.

MR. A. LINDQUIST (Abo)

We have tried to check the thickness of laminates using ultrasonics and it would be very interesting to know what kind of equipment gives the best results. The thicknesses given by the Author are the same as we calculate with viz. 1·1–1·2 mm. for a 450 g/m.^{2} mat. Check tests have also been made determining the tensile strength of the finished laminate where pieces have been cut off for sidelights. The results have all been above the Society's requirements but the builders here in Finland mainly use a combination of mats and rovings in their laminates.

MR. J. I. MATHEWSON (Hong Kong)

At one stage an attempt was made to record the amount of reinforcement used by retaining a small offcut from each piece of reinforcement and using these, a master indicator board was built up, the same effect can be obtained by the use of coloured discs or similar. These methods have now been discarded, however, since it was found that they tended to distract the moulders' concentration from the actual product to that of the recording mechanism.

Control is now exercised as follows:—

Before each new hull type goes into production the materials used in the moulding of the prototype are carefully measured at issue and also the remainder after completion of the mould. The prototype is then checked by calipers and drilling of small holes and when found satisfactory is weighed. Thereafter, for each hull in this series the correct weight of materials for completion of the moulding is issued against the reference number and the hull weighed upon completion. Calipering the top sides and gauging of the

exposed edges in way of cut-outs for sea inlets, exhaust, stern-tube, keel bolts, etc., is then sufficient to assess the correct distribution of materials in all the subsequent hulls.

In addition, for each hull type there is one moulder responsible for its correct construction and incorporation of additional reinforcements, etc., or any other construction features peculiar to this design. When engaged on the construction of a hull type for which he is not responsible he merely acts as one of the moulding gang. In this way all the moulders share the responsibility in turn and this system would appear to offer a good training for the selection of chief moulders, foreman, etc.

AUTHOR

Mr. Christiansen, of Aalborg, would also like to know the latest position of ultrasonics which, as far as I know, is that the only work being done is that by Mr. Lindquist at Abo. I know of no other boatyard where such equipment is being regularly used, simply because the cost is beyond the normal means of the builders. We have tried a more sophisticated paint thickness meter but unfortunately the instrument could not give sufficient accuracy over the large thickness range of 0·25–0·625 inches (6–16 mm.) and several instruments each covering a separate part of this range would have been necessary. In place of the metal plate required with such instruments we intended to use a self-adhesive metal foil as the reflector; this tape would be stuck to the outside of the hull at convenient varied vertical intervals and the instrument probe would have been simply run down the inside of the hull in way.

Mr. Mathewson's remarks on one moulder of a team being responsible for the special features of a particular type are very relevant and this idea could well be adopted by many firms. A similar system operates in one of Mr. May's yards which has about five teams, each team being thoroughly familiar and specialising in only a few models of the many types produced by the firm.

5 . 5 LAMINATE DEFECTS AND SURFACE FLAWS

Mr. G. R. MAY (Headquarters)

The Author is to be thanked for his paper giving a very full coverage of the general procedure for the Survey and inspection of Reinforced Plastic Boatbuilding, the paper leaves very little room for further comment on this medium for the construction of yachts.

In new construction minor defects may be found in way of areas creating moulding hazards by virtue of their shape and accessibility, such as, around the swelling for the stern tube, at ends of hand rail fairings sometimes fitted to the coach roof, and at the outboard edges of the rudder hollow at aft end of the stern post.

A method of testing for voids in the laminate by sounding with a coin has been generally accepted.

Voids and other defects such as areas of dry mat near the surface can be found more easily by sounding with a small hammer which is also much easier on the user's hands when several yachts are being examined at any one time.

In paragraph 5 . 5 . 4 the Author refers to surface cracks as not being structurally important and affecting the boat's appearance only. These cracks, if not attended to when they first occur, could affect the reinforcement through ingress of water and should be dealt with as soon as they appear.

An additional cause of surface pinholing is by excessive use of polyvinyl alcohol (P.V.A.) release agent when applied to the mould prior to fitting the gel coat.

Pre-release of the gel coat has been known to occur in the vicinity of the cove line when a brass convex strip has been used in the mould to form this shape. Materials known to be bad conductors of heat should be used to form these shapes.

Mr. J. I. MATHEWSON (Hong Kong)

Of all the defects listed crazing and leaching would appear to be the most serious and most disturbing since they are not generally apparent until some considerable period of ageing of the product. Both are related to undercure of the resin and serve to emphasise the need for a satisfactory solution to the problem of assessing the cure manufacture. Can the Author provide any statistics regarding occurrence of major failure?

Mr. W. B. SCHEELINGS (Rotterdam)

Wrinkling is often caused by undercure of the gel coat. Is the following repair considered acceptable?

Grind off the damaged gel coat until the first layer of the lay-up is exposed, and then build up new gel coat until the same level is reached. Finish off by abrading down to smooth surface.

In the case of a coloured gel coat, will it be necessary to re-coat the hull in order to obtain the same colour all over?

This defect has mostly been found in way of anti-skid pattern on decks and is practically always in the centre of the diamond. Does this defect not always occur when the viscosity of the gel coat is too high (entrapped air cannot escape)? Can the Author give some figures for viscosity of gel coats, especially for decks with anti-skid pattern?

AUTHOR

The defects mentioned by Mr. Mathewson are very rarely seen nowadays as the firms are more aware of the reasons for these defects and ensure that such conditions do not arise. From the statistical side, we have no record of any such trouble being found in craft moulded under survey, in fact, apart from collision damage and some poor design details in certain types, there are very few instances of laminate troubles. However, now and again, an unexplainable defect occurs (generally to gel coats) and which would require a chemical examination to determine the cause. I would like to advise surveyors not to over-express an opinion on the cause of these mysterious defects as you can never be entirely certain. The answer very often lies in a simple little slip-up by the moulder rather than in an involved technical explanation.

Mr. Scheelings repair for wrinkling is quite acceptable. Regarding the matching of gel coats, this can never be completely achieved on account of fading, etc., but can be done close enough as to be acceptable to all but the very discerning owner. The gel coat resins are generally thixotropic due to their nature as they are filled with pigments, mineral fillers and must not be subject to excessive drainage. The solution is not as much one of the correct viscosity but by applying the first brushload by a stippling action which drives the air out, then stroking to ensure an even coat of gel. Another solution which most moulders now adopt is to change the anti-skid pattern to one which does not have the pyramid

form or by using anti-skid resin paint on top of the gel surface.

6 . 1 . 1—Repairs—General

Mr. J. LEATHERBARROW (Headquarters)

I would first like to add my appreciation to that already recorded for an excellent and very necessary paper.

I would like to query procedure in the event of damage to a plastic lifeboat.

Let us assume one or more plastic boats have been damaged on voyage, either by contact or perhaps heavy weather. The damage sustained of the order of fracturing and holing locally. Obviously, the Safety Equipment of the vessel is very much affected, the questions now arising:—

(a) Assuming there are boat builders or repairers available locally with capacity and facilities required to effect repairs, should the surveyor insist on the lifeboat (or boats) being stripped, unshipped and conveyed to works for repair. If necessary detaining the vessel whilst repairs are being completed? Alternatively, would it be possible to effect repairs in place, with the resultant saving in time and cost, or possibly overcoming the problem of the repairer's workshops being full.

(b) In the absence of specialists on plastic boat work, would it be in order to accept, even as a temporary repair an effort of the local ship repairers if available, if not available an attempted repair by the ships' engineer carpenters by means of a "Thistlebond" repair kit or similar?

(c) Presumably any repairs to plastic lifeboats would be "subject" to future surveys and details of repairs effected would be available to a surveyor before he commenced a S.E. Survey

AUTHOR

In the case of damage on voyage a repair should be effected as soon as possible. Depending on the time from a convenient port, this repair need only be of a temporary nature such as plugging the hole with canvas, a bolted metal or plywood plate, etc., and the boat sent ashore at the first possible opportunity. However, there is nothing to stop the carpenter having a crack at a more permanent repair with a resin/glass kit. Provided he takes the necessary precautions of correct preparation, adequate bonding area, area dried, dry glass, local heat, protection from draughts, etc., the repair should be entirely satisfactory.

Major repairs, such as a crushed bulwark or fractured hull, will normally be done by a repair yard. These can be done in a matter of hours when the case demands and the ship could be off on the next tide. Such repair work would be very lucrative and a spot in the moulding shop can also be found on such occasions. Extensive major damage would normally mean a new lifeboat, the damaged boat being returned for re-building if considered worthwhile.

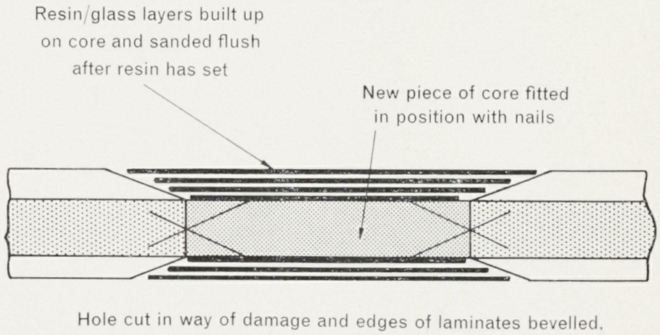
6 . 1 . 3—Major Repairs

Mr. S. SANDERSON (Copenhagen)

I am not sure that the "alternative method" of laying up the shaped pieces of reinforcement (page 10, top of 2nd column) is as good as the method mentioned previously. It might not give the same satisfactory impregnation and consolidation with the existing hull, as far as our experience goes, as when the laminates are laid up separately. The method is considered too "cheap" if it is not done more carefully than can be expected under normal working conditions.

Mr. W. B. SCHEELINGS (Rotterdam)

We may expect in future that for large boats that sandwich construction will be adopted. The method of repair in case of serious damage to outside or inside laminate only, can be carried out in a similar manner to that shown in Fig. 7 where the damaged laminate has been removed to the core. Eventually the core will be locally built up to original thickness. In case, however, that the laminate is holed the damaged part has to be cut out and the repairs could be carried out as follows:—



Repair to sandwich laminate.

Is the Author of the opinion that the above repairs are acceptable and that most repairs can be carried out without making temporary backing plates? (In complete agreement.—Author.)

6 . 2 . 1—Surface Preparation for Painting

Mr. W. L. HOBBS (Southampton)

For surface preparation prior to painting, after removing the mould release agents, the usual procedure is to rub down with "Wet and Dry" abrasive paper of about 280 grade, as this provides the smooth mat finish so desirable for forming a key for the paint—the old No. 0 glass paper is now a thing of the past.

I have not yet seen any attempts made to remove old paint from a glass reinforced plastic hull other than by rubbing down and am rather worried as to what will happen when some unwary owners try paint remover.

Mr. A. LINDQUIST (Abo)

The surface preparation is very important when painting a fibre-glass boat. The adhesion of any type of paint is good only if the surface is well cleaned from wax and PVA and the surface well rubbed down. The paint will certainly peel from a surface which is not clean.

6.2.2—Type of Paint

Mr. A. LINDQUIST (Abo)

Regarding the use of epoxy paints I would strongly recommend lambskin rollers to be used where possible. It is much easier to obtain a nice surface using a roller than a brush.

6.2.3—Fouling of the Bottom

Mr. A. LINDQUIST (Abo)

A system which I believe is quite good is to use an etching zinc chromate primer (as used on aluminium) and on top of that any ordinary anti-fouling paint.

In preparing these series of papers dealing with the construction of reinforced plastic boats, I would like to thank all my colleagues who rendered assistance, and in particular

W. L. Hobbs	–	Southampton
S. Janzen	–	Gothenburg
A. Lindquist	–	Abo
J. M. Mathewson	–	London Headquarters
G. R. May	–	London Headquarters
S. Sandersen	–	Copenhagen (now retired)
W. B. Scheelings	–	Rotterdam

Printed by Lloyd's Register of Shipping at Garrett House, Manor Royal, Crawley, Sussex, England